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**Corrosion-Resistance of Materials  
in the Aggressive Media of Chemical Processes**

**G. Ya. Vorob'yeva**

**Source:** Korrosionnaya Stoykost' Materialov (v Agressivnykh Sredakh Khimicheskikh Proizvodstv), Moscow, 1957, pages 1-11 and 74-159.

This book is a collection of published data, partially supplemented by experimental data of the author, on the properties and corrosion resistance of the most widely used metallic and nonmetallic structural materials and protective coatings.

The book is intended as a reference aid for designers and engineering-technical personnel of chemical plants and scientific research institutes.

## CONTENTS

Foreword . . . . .	1
Introduction . . . . .	2
Chapter II. NONMETALLIC CORROSION-RESISTANT MATERIALS . . . . .	10
Polymerization plastics . . . . .	13
Polycondensation plastics . . . . .	40
Bituminous-asphaltic plastics . . . . .	48
Materials based on rubbers . . . . .	50
New types of elastomers . . . . .	57
Colored-lacquer materials . . . . .	70
Polymeric cementing materials . . . . .	73
Wood, carbon, graphite . . . . .	74
Nonmetallic materials of inorganic origin . . . . .	77
Nonmetallic protective coatings . . . . .	84
Literature . . . . .	96
Chapter III. CORROSION-RESISTANCE OF METALS AND NONMETALLIC MATERIALS . . . . .	101

## FOREWORD

One of the important goals set forth by the party and government is the development of every phase of the chemical industry.

In connection with this, special emphasis is placed on the development of a vigorous chemical machine-construction industry, which will be called upon to provide the country with equipment capable of withstanding various aggressive media.

Along with metals, other materials will be used widely as structural materials and protective coatings. By 1970, for example, plastics will make up an appreciable part of all the materials used in the construction of chemical equipment.

The domestic literature is almost completely lacking in reference manuals containing data on the corrosion resistance of metals and nonmetallic materials.

In this book an attempt is made to fill this gap and to help the specialist in the selection of a corrosion-resistant material or protective coating. Besides the description of the corrosion properties of the materials most widely used in the chemical industry, information about other properties is included as well. The feasibility of using these materials under various conditions is also indicated.

The data included in the tables of corrosion resistance are taken from literature sources and partially supplemented by experimental investigations (as indicated in the footnotes).

Each evaluation of the corrosion resistance of a metal, alloy or non-metallic material is obtained as a result of the generalization of at least a few concurrent data from different sources. The principal sources included the most complete contemporary domestic and foreign handbooks of the corrosion resistance of materials: Dyatlova, V. N., "Korroziionnaya Stoykost' Metallov i Splavov", 1964 ed.; Batrakov, V. P., "Korroziya Konstruktsionnykh Materialov v Agressivnykh Sredakh", Oborongiz, 1952; "Korroziionnaya i Khimicheskaya Stoykost' Materialov", Handbook edited by N. A. Doliezhalya, Mashgiz, 1954; Mantell, C. L., "Engineering Materials Handbook", London, 1958; Rittir, F., "Korrosionstabellen Metallischer und Nichtmetallischer Werkstoffe", 1952, 1956; Dechema Werkstoff-Tabellen, 3rd edition, 1953-1964, and also other references listed in the bibliography.

When the evaluation of the corrosion resistance of a certain material involves information from the literature which is inconsistent, this is indicated in a footnote to the appropriate table.

The author hopes that this book will be useful not only to designers and technicians, but also to all those working in the area of the study of corrosion processes.

## INTRODUCTION

The equipment of most chemical processes is used under rigorous conditions. It is subjected to the simultaneous influence of aggressive medium, high temperature, pressure, and also mechanical effects (grinding, wearing, etc.). Under such conditions, metals\* are subjected to corrosion (disinte-

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\* Here and below the term "metal" refers to alloys as well as pure metals.

gration caused by an external medium) and, to a lesser degree, erosion

(disintegration caused only by mechanical action).

Corrosion may be either electrochemical (most prevalent) or chemical (for example, the action of dry gases or liquid organic compounds on metals at high temperatures, under which conditions the electrochemical processes cannot occur because of the absence of active ions).

The classification of various types of corrosion is illustrated in Fig. 1. Liquid corrosion occurring in electrolytic solutions is a form of electrochemical corrosion. The corrosion processes which take place in the atmosphere and the soil due to the presence of moisture are also classes as electrochemical, although they differ in a number of details.

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Legend for Fig. 1:

- A - Classification of the corrosion of metals
  - B - By the kind of corrosion medium
  - C - By the nature of destruction
  - D - By the kind of process
- 

Gaseous corrosion, which occurs chiefly at high temperatures, is a form of chemical corrosion. It is most frequently a result of the oxidation of metals by oxygen. The rate of gaseous corrosion depends on the nature of the metal, the type of process, and also the protective properties of the oxide films which form on the metal. For iron (steel), for example, the oxide layer is protective up to a temperature of 575-600°C; at higher temperatures it becomes porous, loses its protective properties, and allows the rate of corrosion of iron to increase sharply.

In addition to oxygen, the following gases are very destructive to steel

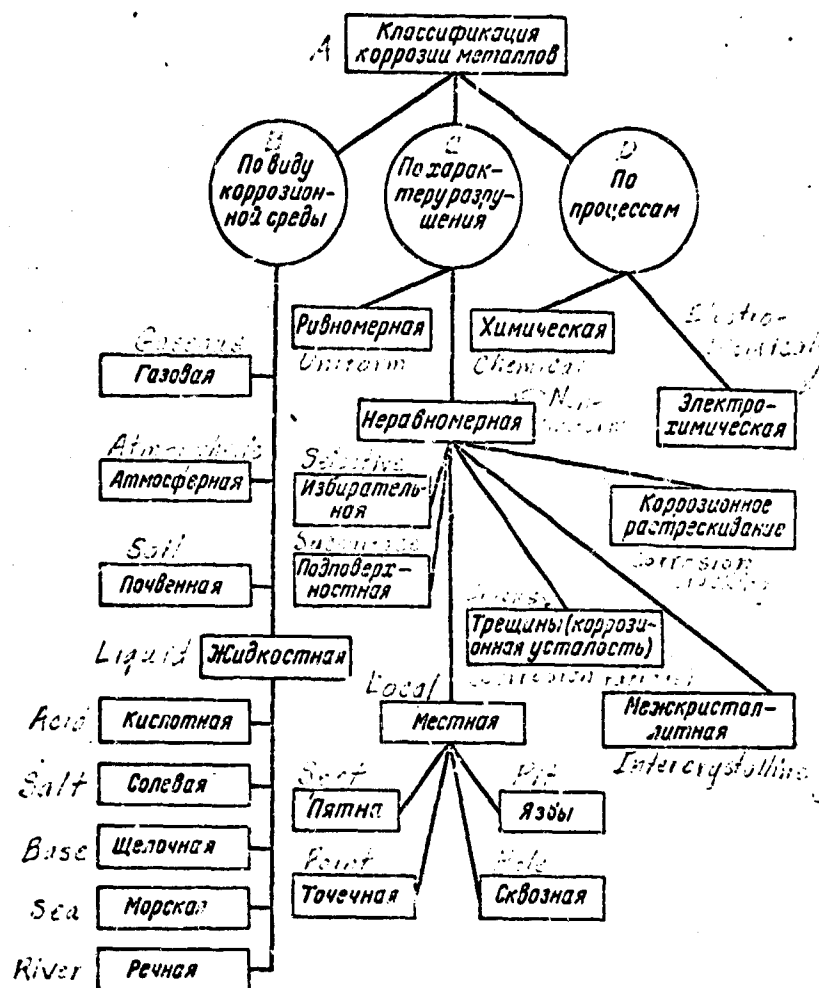


Fig. 1. Classification of the corrosion of metals.

and non-ferrous metals at high temperatures: sulfur dioxide, hydrogen sulfide, hydrogen chloride, chlorine, hydrogen (under pressure) and others. Chlorine and hydrogen chloride are the most dangerous; as with other gases, the intensity of their action depends on the properties of the metal and the temperature of the reaction. Thus, dry chlorine corrodes steel at temperatures above  $200^{\circ}\text{C}$ ; hydrogen chloride above  $300^{\circ}\text{C}$ ; sulfur dioxide, sulfur vapor, nitrogen dioxide  $\sim 500^{\circ}\text{C}$ ; and hydrogen sulfide above  $500^{\circ}\text{C}$  (at temperatures below  $500^{\circ}\text{C}$  hydrogen sulfide does not corrode ordinary steels).

The temperatures at which the same aggressive media act on non-ferrous metals are different. Thus, chlorine causes corrosion of copper at temperatures above  $300^{\circ}\text{C}$  and nickel above  $540^{\circ}\text{C}$ . Sulfur vapor and sulfur compounds, especially hydrogen sulfide, begin to attack nickel at  $300^{\circ}\text{C}$ . Hydrogen sulfide has a very strong effect on copper in the presence of atmospheric oxygen, but sulfur dioxide begins to attack copper only at  $700\text{-}900^{\circ}\text{C}$ .

In the presence of water vapor, the gaseous corrosion of all metals is increased sharply and the temperature limits of their utilization in gaseous media are lowered appreciably. Hydrogen is dangerous at high temperatures and pressures (more than 100 atm) since it causes "hydrogenic corrosion" of steel, resulting in its disintegration. It also causes the formation of cracks (hydrogen brittleness) in copper and its alloys.

Depending on the nature of the destruction, corrosion can be classified as follows:

a) uniform; this occurs when the metal is sufficiently thick and the stresses (tension, compression) are distributed uniformly. This type of corrosion has little effect on the mechanical strength of a structure and is evaluated by measuring the loss of mass per unit area of metal or the depth



of corrosion of its surface;

b) non-uniform (in particular, local) corrosion (spots, pits, holes and point corrosion) arises when the metal is not completely passive, when there is non-uniform aeration of indentations, when there are different concentrations of solution at different parts of the metal, when the machining of the metal surface is non-uniform, etc. Thus, point corrosion occurs as a result of the disturbance of isolated regions of the passifying layer, for example at impurity sites. This type of corrosion is especially typical for chromium, aluminum and chrome-nickel steels. Slit corrosion is a variety of local corrosion which is characterized by the increased disintegration of a metal under bearings, at sites of loose connections, in clearances, in threaded joints, etc;

c) selective corrosion is characteristic of brasses, in which one of the components of the alloy (zinc) goes into solution (the phenomenon of dezincing);

d) intercrystalline corrosion occurs as a result of the disintegration of the metal along grain boundaries. It propagates quickly into the interior of the metal and leads to a sharp degradation of its mechanical properties. Under these circumstances the failure of an item may occur unexpectedly, without any change in the external form of the metal.

Intercrystalline corrosion is inherent in many metals; several of them are especially susceptible to this form of corrosion when they are in a stressed condition.

There are qualitative and quantitative methods for the evaluation of corrosion.

The qualitative methods include: external inspection of specimens of the metal after they have been acted upon by an aggressive medium; observation of

the distribution of corrosion products on the surface of the metal, and also noting changes in the solution (turbidity, change of color, appearance of corrosion products in the form of sedimentation, etc.).

In addition to visual examination, more detailed qualitative information is obtained by means of microscopic inspection of specimens subjected to corrosion (especially important for the detection of intercrystalline corrosion). Indicator methods are also used. In this case a substance added to the corrosion medium forms a color when it reacts with metal ions going into solution.

Quantitative methods for the evaluation of corrosion include: measurement of the rate of the corrosion process by a weight or volume method; determination of the mechanical properties of the metal or other material after it has been exposed to an aggressive medium; electrochemical measurements.

The volume method for the determination of corrosion rates is based on the measurement of evolved or absorbed gases. For example, with the hydrogen corrosion meter it is possible to calculate the amount of metal which has gone into solution from the volume of hydrogen evolved.

In the weight method, the mass difference is determined by weighing metal specimens before and after the corrosion tests (with corresponding preliminary treatment of the samples).

In the case of uniform corrosion, a measure of the corrosion resistance of a metal is the quantity of metal which goes into solution. This is determined either from the loss of mass of the sample, referred to unit surface (1 m<sup>2</sup>, 1 cm<sup>2</sup>) and unit time (hr, day, year), or from the depth of corrosion (mm/yr).

The weight index, designated by the letter  $K$ , is expressed in the units

$g/(m^2-hr)$  and is calculated from the formula

$$K = \frac{\text{loss (or gain) of mass}}{(\text{surface of sample})(\text{duration of test})}$$

The depth index, sometimes called the penetrability, is designated by the letter P; it is expressed in units of mm/yr and is calculated from the formula

$$P = \frac{8.76 K}{d}$$

where P is the loss in mm/yr, determined by weighing the sample before and after the test, and d is the density of the metal being tested ( $g/cm^3$ ).

A 5-point scale is used for the evaluation of the corrosion resistance of metals by the mass method, whereas the depth index is rated on a 10-point scale (GOST 5272-50). The 5-point scale is used more frequently, in accordance with generally accepted practice for the evaluation of the corrosion resistance of metals in other countries. The difference consists of the fact that the metal is usually considered to be unstable already when the rate of corrosion is greater than 3.0 mm/yr. The 5- and 10-point scales used to evaluate the stabilities of metals are given in Table 1.

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Legend for Table 1:

A - 5-point scale; B - 10-point scale; C - stability group

D - loss of mass,  $g/(m^2-hr)$ ; E - rate of corrosion, mm/yr;

F - very stable; G - stable; H - comparatively stable;

I - slightly stable; J - unstable; K - completely stable;

L - decreased stability.

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The corrosion processes of nonmetallic polymeric materials differ from those of metals and their mechanisms have not yet been studied sufficiently.

А Пятибалльная шкала		Рейт. Балл	В Десятибалльная шкала	
С группа стойкости	потери массы $\Delta$ г/(м <sup>2</sup> ·ч)		С группа стойкости	скорость коррозии $E$ мм/год
Ф Очень стойкий	<0,10	1	К Совершенно стойкий	<0,001
Г Стойкий	0,10—1,0	2	В Очень стойкий	0,001—0,005
Н Сравнительно стойкий	1,0—3,0	3	Ф Стойкий	0,005—0,01
И Малостойкий	3,0—10,0	4	С Стойкий	0,01—0,05
Ж Нестойкий	>10	5	С Стойкий	0,05—0,10
		6	Пониженно стойкий	0,10—0,50
		7	С Стойкий	0,50—1,0
		8	И Малостойкий	1,0—5,0
		9	Ж Нестойкий	5,0—10,0
		10	Ж Нестойкий	>10,0

Table 1. Classification of the stability of metals by 5- and 10-point scales.

Thus, whereas the corrosion of metals occurs principally at the phase boundary between the metal and the medium, the swelling and dissolving of a polymeric material under the influence of a corrosion medium extends to the interior of the material and depends on diffusion processes. In the latter case, the determining factors are the nature of the material and the corrosive medium (concentration, temperature, length of exposure, etc.). The action of chemical reagents on polymeric materials may cause their destruction and lead to a loss of their initial properties. The action of some media (concentrated acids, strong oxidizers, etc.) causes rubbers to "age" gradually. That is, they lose their elasticity, harden and become brittle. On the other hand, under the influence of other media they swell, increasing in volume until they dissolve, and their strength characteristics decrease sharply. Some media extract the binding or separating ingredients from resin mixtures. This in turn impairs other properties of the resin, in particular its strength. Aggressive media may cause lacquers and enamels to lose their luster, become brittle, and crack. This may weaken the adhesion to the metal to the point where the film of material scales off.

The corrosion of materials of inorganic origin involves a gradual disintegration under the influence of stresses. These stresses are caused by the formation of new compounds of larger volume in the pores of these materials or by the interaction of individual components with the medium (for example,  $\text{SiO}_2$  with bases).

## Chapter II

### NONMETALLIC CORROSION-RESISTANT MATERIALS

Nonmetallic, chemically-stable materials have been used widely in recent years as corrosion-resistant structural materials and protective coatings<sup>1</sup>. This makes it possible not only to conserve non-ferrous metals, expensive high-alloy steels and alloys, but also to carry out industrial processes for which metallic equipment is not suitable.

For example, at present nonmetallic materials (mainly plastics) are used for equipment construction in the USA and FRG (Federal Republic of Germany) in the amounts of 21 and 16%, respectively (of the total amount of structural materials used).

Along with plastics, there has been a large expansion of the use of nonmetallic materials based on silicates, which are used to prepare glass tubing and enameled and ceramic equipment.

All the nonmetallic corrosion-resistant materials can be divided into two classes: materials of organic and inorganic origin<sup>2,85</sup>.

The selection of materials of the organic class, in contrast to the inorganic class, is extremely large and is growing continuously.

Fig. 12 shows the classification of nonmetallic materials of organic origin in schematic form.

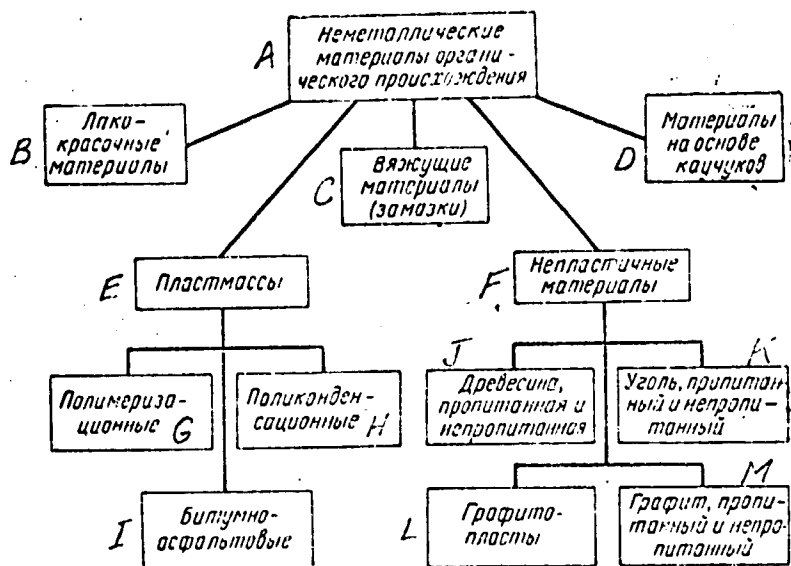


Fig. 12. General classification of nonmetallic materials of organic origin.

Legend for Fig. 12:

A - Nonmetallic materials of organic origin; B - Colored-lacquer materials; C - Binding materials (cements); D - Materials based on rubbers; E - Plastics; F - Non-plastic materials; G - Polymerization; H - Polycondensation; I - Bituminous-asphaltic; J - Wood pulp, treated and untreated; K - Carbon, treated and untreated; L - Graphitoplasts; M - Graphite, treated and untreated.

On the basis of the variety of materials and properties available, the extent of utilization and significance, plastics occupy the most important position among nonmetallic corrosion-resistant materials<sup>3-9,86</sup>. These are materials which are based on natural or synthetic compounds and which can be

molded with the application of heat and pressure. They retain their molded shape after cooling.

Depending on the method of preparation, plastics can be classified as polymerization or polycondensation products.

Plastics are subdivided into thermoplastic and thermoreactive groups on the basis of the type of polymeric compounds. Thermoplastics contain high-molecular-weight polymers or copolymers of linear structure (polyethylene, polystyrene, polyvinyl chloride, etc.). Their composition also includes plasticizers and stabilizers. When thermoplastics are heated, they become soft and plastic; when they are cooled, they return to the solid elastic state and regain their original properties. Thermoreactive plastics contain low-molecular-weight polymers. They harden through the formation of polymers with three-dimensional structures when they are heated or when they are exposed to catalysts (phenolformaldehyde and carbanide resins) or hardeners (epoxide resins, polysiloxanes, unsaturated esters).

When the temperature is increased, thermoreactive plastics also become plastic at first. However, they undergo a transformation to a viscous state, then harden, and finally become infusible and insoluble (due to the formation of a reticulated structure). They do not return to the plastic state.

Thermoreactive plastics differ in the type of filler which is used to give them specified mechanical (strength) and other properties:

1. Powdered (wood flour, asbestos powder, quartz flour, etc.).
2. Fibrous (cotton floss, asbestos fiber, glass fiber).
3. Lamellar (glass or cotton fabric).
4. Plastics with glass filler (fiber, fabric) with the general designation "fiberglass".

## Polymerization Plastics

This category includes plastics obtained by polymerization and copolymerization<sup>10</sup>. Almost all the plastics of this group (except asbovinyl) are thermoplastics. The characteristics and properties of polymerization plastics are listed in Table 27.

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### Legend for Table 27:

A - Properties; B - Polyisobutylene PSG; C - Polyethylene; D - high pressure (low density); E - low pressure (high density); F - Polypropylene; G - Polystyrene; H - block; I - emulsion; J - Polymethylmethacrylate; (organic glass); K - Viniplast (polyvinyl chloride); L - Fluoroplasts; M - Asbovinyl;

1 - original monomers; 2 - GOST or TU (Translator's note: The symbols appearing in this line and elsewhere throughout the book are standards and specifications of various Soviet agencies); 3 - TU MKhP; 4 - VTU MKhP; 5 - MRTU; 6 - STU; 7 - TUM; 8 - VTU; 9 - FP; 10 - density,  $\text{g/cm}^3$ ; 11 - specific resilience,  $\text{kgf-cm/cm}^2$ ; 12 - does not break; 13 - not less than; 14 - limit of strength,  $\text{kgf/cm}^2$ ; 15 - tension; 16 - compression; 17 - flexure; 18 - relative elongation at rupture, %; 19 - Brinell hardness,  $\text{kgf/mm}^2$ ; 20 - by Shore; 21 - Martens thermostability,  $^{\circ}\text{C}$ ; 22 - by Vicat; 23 - frost resistance,  $^{\circ}\text{C}$ ; 24 - lower than; 25 - softening temperature,  $^{\circ}\text{C}$ ; 26 - higher than; 27 - thermal conductivity,  $\lambda \times 10^4$ ,  $\text{cal/(cm-sec-deg)}$ ; 28 - coefficient of linear thermal expansion,  $\alpha \times 10^6$ ; 29 - specific volume electrical resistance,  $\text{ohm-cm}$ ; 30 - polymer; 31 - electric strength,  $\text{volt/mm}$ ; 32 - dielectric permeability (at 50 Hertz); 33 - tangent of angle of dielectric losses (at 50 Hertz); 34 - Water absorption in 24 hr, %; 35 - temperature limit of utilization,  $^{\circ}\text{C}$ .



Показатели А	Полибути- лен ПБ	Свойства		F Полипропилен	G Полноты		J Полноты- стакрилат (органическое стекло)	K Выпласт (полипро- пилен)	L Фторопласты			M Асбонит
		Дли- на высо- кой плот- ности	Дли- на высо- кой плот- ности		H блочный	I эмуль- сион- ный			3	3M	4	40
Изомеры моно- меров	$\text{CH}_2=\text{C}(\text{CH}_3)-\text{CH}_2-\text{CH}_3$	$\text{CH}_2=\text{CH}_2$	$\text{CH}_2=\text{CH}_2$	$\text{CH}_2=\text{CH}-\text{CH}_3$	$\text{C}_6\text{H}_5-\text{CH}_3$	$\text{CH}_3$	$\text{CH}_2=\text{C}(\text{CH}_3)-\text{COOCH}_3$	$\text{CH}_2=\text{CHCl}$	$\text{CF}_3-\text{CFCl}$	$\text{CF}_3-\text{CF}_2$	$\text{CF}_3-\text{CF}_2$	$\text{CH}_2=\text{CH}-\text{CH}_2-\text{CH}_3$
ГОСТ или ТУ	ТУ МХП 2567-52	ТУ МХП 4158-52 и 6-65- 6-65-889-64	ТУ МХП 4158-52 и 6-65- 6-65-889-64	ТУ 36-13-925- 2 63	ГОСТ 9440-60 ТУ 4219-52	ТУ 1827-51 ГОСТ 9440-60	ТУ МХП 26-54	ТУ МХП 3823-53 ГОСТ 9039-61	ТУ МХП 3823-53 ГОСТ 9039-61	ТУ МХП 3823-53 ГОСТ 9039-61	ТУ МХП 3823-53 ГОСТ 9039-61	ТУ МХП 3823-53 ГОСТ 9039-61
Плотность, г/см <sup>3</sup>	1,33-1,42	0,92-0,93	0,94- 0,96	0,90-0,91	1,1	1,05	1,8-1,2	1,38-1,43	2,09	2,02	1,7	1,4-1,5
Ударная прочность, кгс/см <sup>2</sup>	0,60	16	16	60-85	15-20	15-22	не менее 12	100-180	20-160	не ме- няется	100-160	2,9

Table 27. Physical and mechanical properties of polymerization plastics.

Показатели	Полиэфиры ПЭ	С Полиэтилен		F Полипропилен	H блочный	рол	J Полиэтил-метакрилат (органическое стекло)	K Винилласт (поливинилхлорид)	L Фторопласты				M Асбобинил
		высокого давления (низкой плотности)	низкого давления (высокой плотности)						3	3M	4	40	
1 Прочность, кг/см <sup>2</sup>	30-70	120-160	220-400	300-360	350-500	350-400	650	400-600	300-400	250-300	140-200	300-350	130-215
2 Прочность при растяжении, кг/мм <sup>2</sup>	—	120-145	400-450	600-700	800-1000	1000	700-850	600-1000	500-570	—	120-200	—	200-350
3 Прочность при сжатии, кг/мм <sup>2</sup>	—	120-170	200-450	800-1100	850-1000	1000	600-650	900-1200	600-800	350	110-140	355	130-300
15 Относительное удлинение, %	300-500	150-500	200-800	500-700	1,5-3,5	1,5-3,5	2,5	10-25	30-200	200-250	250-400	90-180	—
16 Твердость по Шору	40-67 (по Шору)	43-52	70-120	70-95	18-20	20	18-24	15-18	10-13	7,8-8	3-4	5-3	18-25
17 Теплоустойчивость по Мартенсу, °C	—	60	75	100-110	80	80	60-70	65	70	—	100-110	120-150	150-200
2,5 Морозостойкость, °C	—55	-70	-60	-35	Ниже -20	Ниже -20	-50	-20	-195	—	200	—	-50
26 Температура размягчения, °C	—	110-170	120-150	160-170	100	100	120-125	160-170	208-210	—	140-150	—	—
27 Теплопроводность, Вт/см·град	—	7,0	9,6	3,3	1,9	1,9	3,5-6,0	3,9	1,4	—	5,9-6,0	—	1,3
28 Коэффициент линейного температурного расширения, 1/°C	—	22-55	10,0	11,1	6,0-6,2	6,0-6,8	8-12	6-7	6-12	—	8-21	—	2,4-3
29 Удельное объемное электрическое сопротивление, Ом·см	1018-1018 (полимера)	1017	1017	3,5-1014	1018-1017	1018-1015	1018-2-1013	1018	1,2-1018	2-1017	(1,2-2,9)·1016	—	—
30 Закалка, кг/мм	15-23 (полимера)	45-60	45-60	30-32	20	20	25-40	15-45	13-15	23-25	25-27	—	—
31 Диэлектрическая проницаемость (при 50 эд)	2,25-2,35 (полимера)	2,2-2,3	2,2-2,3	2,0-2,5	2,6	2,7-2,8	3,5-3,6	4,1	3,0	3,0	1,9-2,2	—	—
32 Удельная диэлектрическая потеря (при 50 эд)	0,0003-0,0005 (полимера)	0,0003	0,00014	0,0002-0,005	0,00045	0,002	0,02-0,06	0,01	0,015	0,012	0,0002	—	—
33 Влагопоглощение, %	0-0,05	0,01	0,01	<0,01	0,005	0,07	0,3	0,3-1,0	0,0	0,0	0,0	0,0	0,5-1,0
34 Температурный коэффициент линейного расширения, 1/°C	80	80-100	100-110	140-160	60-70	60-70	80	60	125	180	250	150-180	110-120

Table 27 (continued)

Polyisobutylene is a rubber-like product with molecular weight from 2000 to 80,000. It is obtained by the continuous polymerization of isobutylene with a  $\text{BF}_3$  catalyst at temperatures from - 80 to - 100°C in the presence of liquid ethylene (refrigerant and solvent for the monomer). Polyisobutylene is resistant to moisture and weak acids and bases. It is soluble in hydrocarbons and carbon disulfide and insoluble in lower alcohols and complex ethers. It is unstable to the action of sunlight and ultraviolet radiation in the presence of atmospheric oxygen.

High-molecular-weight polyisobutylene is manufactured in four grades (VTU 1655-54): P-85, P-118, P-155, P-200; low-molecular-weight polyisobutylene is designated P-20 (TU 1761-54r). Grades P-200 and P-155 are used as corrosion-resistant material, filled with carbon black and graphite and manufactured, according to TU 2937-52, in the form of a sheet coating material, "PSG brand sheet polyisobutylene". Polyisobutylene coatings may be used independently for protection from corrosion or as impenetrable sublayers for various kinds of coatings (at temperatures up to 100 °C). The great advantage of PSG polyisobutylene is its good adhesion to metals (without annealing) with the cements 88 or 88N. Sheet polyisobutylene is well-known abroad under the trademark "opanol".

Polyethylene<sup>11,12</sup> is a thermoplastic polymer which is produced by the polymerization of ethylene. The following polyethylenes are obtained, depending on the conditions: high-pressure (PVD), low-pressure (PND) and medium-pressure (PSD). The difference in the mechanism of polymerization of ethylene under different pressures results in the formation of polymers with dissimilar structures and properties.

High-pressure polyethylene is distinguished by low density; the degree

of crystallinity amounts to  $\sim 65\%$  and the crystal size is  $190 \text{ \AA}$ . Low-pressure polyethylene is characterized by high density; the degree of crystallinity is  $84\text{--}87\%$  and the crystal size is  $360 \text{ \AA}$ . Medium-pressure polyethylene has increased density and crystallinity, amounting to  $93\%$ .

Polyethylene is highly resistant to a variety of aggressive media (acids, bases, salt solutions and various organic liquids). At elevated temperatures it swells and even dissolves in benzene, toluene, etc. It ages under the influence of heat, ultraviolet radiation and atmospheric oxygen.

Several grades of high-pressure polyethylene are manufactured (according to MRTU 6-05-889-64). The designation "P2" indicates that the material in question is low-density polyethylene ( $0.92 \text{ g/cm}^3$  nominally). The three numbers following are ten times the index of fusion and the terminal letter stands for the primary field of application. For example, P2030-K is low-density polyethylene (PVD) which has index of fusion  $3.0 \text{ g/10 min}$  and which is designed for insulating conductors and general-purpose cables.

Low-pressure (i. e., high-density) polyethylene is manufactured according to MRTU 6-05-890-64 with the following designations, depending on the subsequent method of fabrication: L - for casting under pressure; P - compression molding; E - extrusion; V - blowing; N - dusting and fusing on of protective coatings. These letters follow the numbers showing ten times the index of fusion. The initial designation "P4" stands for high-density polyethylene ( $0.94 \text{ g/cm}^3$ ).

The characteristics of high- and low-pressure polyethylene are shown in Table 27. Polyethylenes have very good engineering properties, and they may be used to fabricate items by casting, extrusion and compression molding. They can be machined and they can be cemented and welded readily.

The combination of ease of processing and high chemical stability makes possible the widespread use of polyethylene in many branches of technology. In the chemical industry this includes applications as a structural material and also for the preparation of protective coatings.

Polyethylene is manufactured by many foreign companies under various trade names. The names of several brands produced in various countries are listed below:

England . . .	alcotene, polytene, telcotene
FRG . . . . .	lupolene, hostalene, vestolene
Italy . . . .	fertene, rotene
France . . .	plastilene, lionitene
USA . . . . .	marlex, alatone

The selection and purpose of finished and semifinished polyethylene items manufactured by domestic industries are shown in Table 28.

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Legend for Table 28:

1 - cable polyethylene (high pressure); 2 - for insulating conductors, cables, radio apparatus; 3 - packing material (composition of polyethylene with polyisobutylene); 4 - chemically stable packing and seals; 5 - polyethylene films; 6 - electrically insulating packing and wrapping material; 7 - hoses and tapes; 8 - polyethylene tape with adhesive layer; 9 - for fastening polyethylene films; 10 - sheets and plates; 11 - electrically insulating materials; 12 - polyethylene pressure tubing (high-pressure polyethylene); 13 - for transporting aggressive liquids; 14 - same (low-pressure polyethylene); 15 - same; 16 - fittings for pipes (high-pressure polyethylene); 17 - same (low-pressure polyethylene); 18 - bottles, vials, flasks and other containers;

19 - for storing and transporting aggressive liquids.

Наименование	ГОСТ или ТУ	Назначение
1 Полиэтилен кабельный (высокого давления)	ТУ МХП 2524—53	Для изоляции проводов, кабелей, радио-аппаратуры
3 Прокладочный материал (композиции полиэтилена с полиизобутиленом: ПОВ-20 ПОВ-30 ПОВ-50 ПОВ-67)	ВТУ МХП 4440—55 ВТУ ЛСНХ 33080—60 ТУ МХП 2747—51	В качестве химически стойких прокладок и уплотнений
5 Пленки полиэтиленовые	ВТУ МХП 4430—55 ГОСТ 10354—63	В качестве электроизоляционного прокладочного и упаковочного материала
8 Лента полиэтиленовая с липким слоем	ВТУ МХП М 709—55 ВТУ М 621—55	Для рукавов и лент
10 Листы и плиты	СТУ-30-14222—64 ВТУ ЛСНХ 33059—60	Для склеивания полиэтиленовой пленки
12 Трубы полиэтиленовые напорные (из полиэтилена высокого давления)	МРТУ 6-05-918—63	В качестве электроизоляционных материалов
14 То же (из полиэтилена низкого давления)	МРТУ 6-05-917-63	Для транспортировки агрессивных жидкостей
16 Фасонные части трубопроводов (из полиэтилена высокого давления)	МРТУ 6 М 857—61	То же
17 То же (из полиэтилена низкого давления)	МРТУ 6 М 858—61	То же
15 Бутылки, флаги, флаконы и прочие объемные изделия	ВТУ ЛСНХ 33018—58	Для хранения и транспортировки агрессивных жидкостей

Table 28. Selection of finished and semifinished polyethylene items and their purposes.

Polypropylene, like polyethylene, is a thermoplastic polymer. It is a product of the polymerization of propylene. Polypropylene is characterized by a high degree of crystallinity (95%) and a higher melting point than polyethylene (160-170°C). It has distinct advantages over polyethylene: higher strength, thermal stability, impermeability to gas and vapor, resistance to oxidation and the action of aggressive media. However, polypropylene has

an appreciably lower frost resistance than polyethylene. In order to increase its frost resistance, polypropylene is modified by using other olefins. For example, a copolymer of ethylene and propylene (SEP) has the same frost resistance as polyethylene.

The methods used to process polypropylene and polyethylene are analogous, but polypropylene is somewhat harder to cement than polyethylene. Polypropylene may be used to make tubing, parts of electrical and mechanical equipment, molded and cast items, and textiles. It can also be used to make industrial films and fibers which are very impermeable to gases. Polypropylene is produced as a white powder, suitable for processing, and in granular form (colored and uncolored) under five brands: PP-1 - for processing by casting under pressure; PP-2 and PP-4 - for processing by the method of extrusion; PP-3 and PP-5 - for compression molding.

As production volumes increase, polypropylene will undoubtedly be used more and more in anticorrosion technology. It is most well known abroad under the name "moplene".

Polystyrene is a thermoplastic polymer which is produced by polymerizing styrene. Polystyrenes can be classified as block, suspension or emulsion, depending on the method of polymerization. It has high chemical stability and excellent dielectric properties, but it has inadequate thermal stability and increased brittleness under the influence of impact loads. Block and suspension polystyrenes are readily processed by the methods of compression molding, pressure casting and extrusion. Emulsion polystyrene cannot be cast under pressure very successfully, so it is most often used for making foam articles and jacketing blocks. When styrene is copolymerized with other monomers (for example, acrylonitrile,  $\alpha$ -methyl styrene, etc.), the thermal

and mechanical properties of the polymer are improved appreciably. The plastics designated SN, SN-28 and SN-20, obtained by copolymerizing styrene with acrylonitrile, belong to this category. Combining the copolymer SN-20 with the nitrile rubbers SKN-26 and SKN-40 yields the plastic SN-P (stable), which has improved mechanical properties. Combining polystyrene with SKN-18 rubber gives a casting composition designated PKND and shock-resistant polystyrene for processing by extrusion and pressure casting.

The selection and uses of polystyrene and its copolymers are given in Table 29. Polystyrene and its copolymers are marketed in other countries under the following names: "styron", "dylon", "karinex", "kralastic", "cycolac", etc.

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Legend for Table 29:

- 1 - Block polystyrene (brands D and T); 2 - Polystyrene D, for making parts for electrical equipment; polystyrene T, for various industrial products; 3 - Block polystyrene (rolled); 4 - For making electrically-insulating items by compression molding and pressure casting; 5 - Block-polystyrene plates; 6 - For mechanical fabrication of components of high-frequency apparatus; 7 - Emulsion polystyrene (brands A and B); 8 - For electrically-insulating industrial items and for general use; polystyrene B, for making anticorrosion and tropic-stable items; 9 - Emulsion polystyrene (brand C); 10 - For making plastic foams; 11 - Granular emulsion polystyrene; 12 - For making industrial and household items; 13 - Polystyrene film; 14 - For cable manufacture; 15 - Styrene copolymers; 16 - For items with increased mechanical strength and resistance to petroleum ether, oils and sea water; 17 - Casting compositions of brands PKND, PKND-5, PKND-10; 18 - For



items with increased mechanical strength and dielectric properties;

19 - Shock-resistant polystyrene of brands UPP-1 and UPP-2; 20 - For

the fabrication of industrial items by extrusion and pressure casting.

Наименование и марка	ГОСТ или ТУ	Назначение
1 Полистирол блочный (марок Д и Т)	ГОСТ 9440-60	2 Полистирол Д -- для изготовления электротехнических деталей и изделий; полистирол Т -- для различных технических изделий
3 Полистирол блочный (вальцованный)	ТУ М 219-52	Для изготовления 1 электроизоляционных деталей прессованием и литьем под давлением
5 Плиты из блочного полистирола	ТУ МХП 2030-49 и 35-ХП-356-61	Для изготовления деталей высокочастотной аппаратуры механическим путем
7 Полистирол эмульсионный (марок А и Б)	ГОСТ 9440-60	В качестве электроизоляционных технических изделий и для широкого потребления; полистирол марки Б -- для изготовления антикоррозионных и трюмкоустойчивых деталей
9 Полистирол эмульсионный (марки С)	ВТУ МХП М 725-56	Для изготовления пенопластов
11 Полистирол эмульсионный гранулированный	ВТУ МХП М 742-57	Для изготовления технических и бытовых изделий
13 Полистирольная пленка	ТУ МХП М 139-54	Для кабельной промышленности
15 Сополимеры стирола марок СН СН-28 СН-20 СНП гранулированный СНП листовой	ВТУ ЛСНХ 33060-60 ВТУ ЛСНХ 33069-58 ВТУ ЛСНХ 33037-59 СТУ 30-125 14-63 СТУ 30-14149-63	В качестве деталей с повышенной механической прочностью и стойкостью к бензину, маслам и морской воде
17 Литьевая масса марок: ПКНД, ПКНД-5, ПКНД-10	ТУ МХП М-395-53	В качестве деталей с повышенной механической прочностью и диэлектрическими свойствами
Ударопрочный полистирол марок УПП-1 и УПП-2	СТУ 30-15 858-62	Для изготовления технических изделий литьем под давлением и экструзией

Table 29. Selection and purposes of polystyrene and its copolymers.

Polymethylmethacrylate (organic glass) is a thermoplastic polymer which is produced by polymerizing the methyl ester of methacrylic acid. It is manufactured in the form of sheet glass (TU MKhP BU 23-53 and No. 26-54) and compression-molding powder of brands L-1 and L-2 (TU 35-KhP-299-61). Polymethylmethacrylate is characterized by high transparency and mechanical strength, low density, and resistance to gasoline, oils and water. Organic glass is used widely for making windows for aircraft and automobiles, for the preparation of transparent models of experimental apparatus, for medical devices and instruments, watch crystals, etc.

Compression-molding polymethylmethacrylate powders are used to make transparent items with increased stability (to oils, gasoline, alcohol, bases and other chemical reagents). Examples are inspection and gage glasses and other parts of control and measuring devices.

Polymethylmethacrylate is known abroad under the names "plexiglass" (USA, FRG, GDR, France), "perspex" (England) and others.

In addition to the polymerization plastics already considered, there is a special group which is made up of products of the polymerization of halogen derivatives of ethylene. The simplest and most widely used representative of this group is polyvinyl chloride.

Polyvinyl chloride is a thermoplastic polymer which is obtained by the polymerization of vinyl chloride; that is, ethylene in which one of the hydrogen atoms is replaced by chlorine.

If polyvinyl chloride powder is combined with a stabilizer and masticated thermomechanically with heated rollers, the result is a widely known solid material known as "viniplast". Combining polyvinyl chloride with a

plasticizer yields soft polyvinyl chloride masticated rubber.

Viniplast combines high stability in many aggressive media (acids, bases, salt solutions, several organic solvents) with good physical-mechanical and dielectric properties.

In this connection, viniplast is widely used as a construction material for making tubing, valves and couplers, small apparatus, tanks, etc., and also for protective coatings.

The use of viniplast is limited somewhat because of its low thermal stability (60-70°C) and insufficient frost resistance (from - 10 to - 20°C).

Viniplast has good engineering properties: it is readily welded, cemented, molded, pressed, stamped, and adapts well to various kinds of mechanical processing (cutting, milling, boring, etc.).

One of the well known copolymers of vinyl chloride is polyvinylidene chloride ("saran"), which contains >75% vinylidene chloride. Its physical-mechanical properties and chemical stability are superior to those of viniplast. Saran is used for linings and for making corrosion-resistant tubing, fittings, and single fibers.

Table 30 shows the variety of items and purposes of semifinished products produced from viniplast by domestic industries.

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Legend for Table 30:

- 1 - Sheets of brands VN, VP, VNT; 2 - For blower hoses, apparatus, linings; 3 - Tubing, rods and section-shaped bars; 4 - For piping systems, pumps and fittings used in aggressive media; 5 - Flexible tubing (hoses); 6 - For transporting air, oil, gas, water; 7 - Welding rods; 8 - For

filling seams when welding viniplast items; 9 - Fittings; 10 - For drains, bends, tees, cross-connectors, compensators; 11 - Straight-through valves of the "Kosva" type; 12 - For valves in piping systems for aggressive media; 13 - Apparatus and components; 14 - For tanks, vats, spiral tubes, reactors, metering tanks, gas ducts; 15 - Sheet masticated rubber; 16 - For protective coatings and packing; 17 - Packing sheet masticated rubber; 18 - Packing used for aggressive media; 19 - Cable masticated rubber; 20 - For electrical insulation and sheathing for electrical cable; 21 - Sheet masticated rubber for gas apparatus; 22 - Packing for gas apparatus; 23 - Calendered viniplast film; 24 - For electrical insulation and other widely-used items; 25 - Perforated and corrugated; 26 - For electrical insulation; 27 - Packing film V-118; 28 - Covers for protecting machinery; 29 - Film masticated rubber; 30 - For diaphragms, membranes and other parts of gas apparatus; 31 - Polyvinyl chloride insulating tape; PKhL-20, PKhL-30, PKhL-40, PKhL-50; 32 - For repair and splicing of insulation on conductors and cable sheaths; for protection of underground conduits; 33 - Polyvinyl chloride adhesive tape; 34 - For protection of petroleum-gas mains.

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Viniplast is known abroad chiefly under the names "vinidur", "ekadur" and "PVC".

Fluoroplasts<sup>9,13,14</sup> are products of the polymerization of fluorine derivatives of ethylene: trifluorochloroethylene (fluoroplast-3) and tetrafluoroethylene (fluoroplast-4). They are distinguished by very high chemical stability over a wide range of operating temperatures: from - 195 to + 125 + 170 °C for fluoroplast-3 and from - 270 to + 260-300 °C for fluoroplast-4.

Наименование	ГОСТ или ТУ	Назначение
1 Листы марок ВН, ВП, ВНТ	ГОСТ 9659—61	Для вентиляционных труб, аппаратов, футеровки
3 Трубы, стержни и профили	ТУ МХП 4251—54	Для трубопроводов, применяемых в агрессивных средах, и арматуры к ним, насосов
5 Трубки гибкие (шланги)	ТУ МХП М 599—55	Для транспортировки воздуха, масла, газа, воды
7 Прутки сварочные	ТУ МХП 90—48 СТУ 30-12307—62	Для заполнения швов при сварке изделий из винилпласта
9 Фасонные части	ТУ МХП 3480—53	Для отводов, поворотов, тройников, крестовин, компенсаторов
11 Вентили проходные типа «Косва»	ТУ МХП 2420—50	Для запорной арматуры к трубопроводам для агрессивных сред
13 Аппаратура и изделия	ТУ МХП 3866—53	Для ванн, баков, емкостей, реакторов, мерников, газоходов
15 Пластикат листовой	ВТУ МХП 2024—49	Для защитных покрытий, прокладок
17 Пластикат прокладочный листовой	ТУ МХП 3702—59 СТУ 30-12421—62	Для прокладок для агрессивных сред
17 Пластикат кабельный	ГОСТ 5950—51	Для электроизоляции и оболочек электрических кабелей
21 Пластикат листовой для газовой аппаратуры	ТУ МХП 3702—53	Для прокладок для газовой аппаратуры
23 Пленка винилпластовая каландрированная	ВТУ МХП 2025—49 СТУ 30-12281—62	Для электроизоляции и изготовления изделий широкого потребления
25 Перфорированная и гофрированная	ТУ МХП 2023—49	Для электроизоляции
27 Пленка упаковочная В-118	ТУ МХП М 786—57	Чехлы для консервации машин
27 Пластикат пленочный	ТУ МХП 3703—53	Для диафрагм, мембран и других деталей газовой аппаратуры
31 Лента полихлорвиниловая изоляционная ПХЛ-20, ПХЛ-30, ПХЛ-40, ПХЛ-50	ТУ МХП 2898—55	Для ремонта и сращивания изоляции проводов и оболочек кабелей; для защиты подземных трубопроводов
31 Липкая поливинилхлоридная лента	ВТУ ИСНХ Г-1—62	Для защиты магистральных газонефтепроводов

Table 30. Selection and purpose of finished and semifinished products of viniplast.

In terms of its chemical stability, fluoroplast-4 is superior not only to all known plastics, but also to most metals. It is attacked only by molten alkali metals and elemental fluorine and it dissolves only in fluorinated kerosene.

Fluoroplast-3 is somewhat less stable. In addition to the reagents mentioned above, aromatic and some fluorine-containing hydrocarbons also act on it.

However, fluoroplast-4 has the disadvantage that it is hard to work with. Fluoroplast items are fabricated by compression molding in two stages: first it is subjected to high pressure ( $300-400 \text{ kgf/cm}^2$ ) at room temperature, and then it is baked at  $370-380^\circ\text{C}$ .

The chemical inertness of fluoroplast-4 is also responsible for its poor adhesive properties. For this reason it cannot be cemented or welded by the methods normally used for plastics. In recent years they have begun to use welding in the fabrication of items of fluoroplast-4, but, practically speaking, it amounts to baking fluoroplast films and semifinished products at high temperatures ( $380-390^\circ\text{C}$ ). The pieces being welded are heated by means of metal plates which are supplied with electric current.

The technique of flux welding has also been worked out for fluoroplast, making it possible to obtain a welded seam which is almost as strong as the original material. The flux used is a fluorocarbon material (so-called UPI grease) to which fluoroplast powder is added. The welding is done at  $370^\circ\text{C}$  under a pressure of  $3 \text{ kgf/cm}^2$ .

It is even more difficult to cement fluoroplast-4<sup>15</sup>. First the surface is activated with, for example, a solution of metallic sodium in liquid

ammonia<sup>16</sup>, and then the treated fluoroplast-4 surfaces are cemented together or to other materials with ordinary cements. Other chemicals have also been proposed for treating fluoroplast-4 before cementing; for example, a melt of pure potassium acetate (recommended by A. Ya. Korolev, et. al.<sup>17</sup>), heated to ~325°C.

In order to improve the industrial methods of forming fluoroplast-4 and thus widen the range of utility of this material with its unusually high corrosion resistance, various methods have been proposed for modifying polytetrafluoroethylene.

The modified fluoroplast-4D is an aqueous suspension of finely divided fluoroplast-4 powder. It differs from ordinary polytetrafluoroethylene in the form of the particles and the somewhat lower molecular weight<sup>18</sup>. Aqueous suspensions of fluoroplast-4D, stabilized by surface-active materials, are used for the application of coatings and for the preparation of films, impregnations, etc. A paste can be obtained from the aqueous suspension by precipitating the powder and adding benzine, vaseline oil, xylene and toluene. This paste can then be used for fabrication by the extrusion method, the items thus formed being subsequently baked at 370°C. This method is used to make tubing and other items with more complicated cross sections. The same paste may be used for chemically and thermally stable gaskets and packing. The fluoroplast sealing materials FUM (NRTU 6-MS70-62) and packing (VTI 110-62) are widely used for joints, valves and other structural units which operate under conditions of friction, vibrations, high temperatures and aggressive media<sup>19</sup>.

Fluoroplast-40 and fluoroplast-42 are also modified fluoroplasts. They can be formed by compression molding, extrusion and pressure-casting and they

can be welded by heating. They are manufactured in the form of white powder and may be used for the corrosion protection of chemical apparatus, piping, fittings and other items which operate in very aggressive media<sup>20,21</sup>.

The fluorine-containing polymer fluoroplast-26, soluble in organic solvents but chemically stable, was developed to make films, plastic objects and lacquer coatings.

Unlike polytetrafluoroethylene (fluoroplast-4), polytrifluoroethylene (fluoroplast-3) has good engineering properties and can be formed by compression molding, pressure-casting and extrusion, although at relatively high temperatures (200-220°C and higher).

The thermal stability of fluoroplast-3 is not very high (100-120°C). With modified fluoroplast-3M the useful temperature range is extended to 150-170°C<sup>22,23</sup>.

Fluoroplast-3 is supplied to factories in the form of powder or semi-finished products. It is used chiefly to make electrical accessories, packing, membranes, etc., but it is also used for protective coatings for chemical apparatus. The selection of compression-molded and semifinished fluoroplast materials produced by domestic industries is shown in Table 31.

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Legend for Table 31:

- 1 - Fluoroplast-4 (brands A, B and V); 2 - For articles and films which are stable in aggressive media and have good dielectric properties;  
3 - Fluoroplast-4D; 4 - In the form of pastes and dispersions for making tubing by extrusion and for insulating and other coatings for shaped objects; 5 - Fluoroplast-4C (brands II and III); 6 - As chemically stable packing material and dielectric. For making structural items by



Наименование	ГОСТ или ТУ	Назначение
Фторопласт-4 (марки А, Б и В)	ГОСТ 10907-62	В качестве изделий и пленок, стойких к агрессивным средам, с высокими диэлектрическими свойствами
Фторопласт-4Д	МРТУ 6-05-942-64	В виде паст и дисперсий для изготовления экструзионных труб и для получения изоляционных и других покрытий профильных изделий
Фторопласт-40 (марки II и III)	ВТУ ГХК М-817-59	В качестве химически стойкого уплотнительного материала и диэлектрика. Для изготовления конструктивных изделий прессованием (II) и экструзией (III)
Фторопласт-42 (марки В, П и Л)	ВТУ 208-62	Для изготовления прессованных и экструзионных изделий (П), волокон (В) и лаковых покрытий (Л), стойких к агрессивным средам
Заготовки из фторопласта-4	ТУ М-810-59	Для изготовления методом механической обработки электронизоляционных, антифрикционных, уплотняющих и химически стойких элементов конструкций и деталей
Заготовки из фторопласта-4	ВТУ НСНХ 08-59 ТУ 35 XII-605-63	Для изготовления методом механической обработки уплотняющих и антифрикционных изделий
Пластины из фторопласта-4	ВТУ 35-XII-397-62	Для прокладок и диафрагм
Трубы из фторопласта-4	ВТУ № 277-60	Для транспортировки агрессивных жидкостей и газов
Фторопласт-3	МРТУ 6 № 05-946-65	В виде суспензий для антикоррозионных покрытий и для изготовления изделий
Фторопласт-3М (марки А и Б)	МРТУ 6-05-905-63	В качестве защитных покрытий и для изготовления пленок и деталей
Заготовки из фторопласта-3М	ВТУ М-840-61	Для изготовления методом механической обработки уплотнительных и конструктивных деталей
Изделия из фторопласта-3	ТУ М-830-60	В качестве уплотнительных элементов конструкций
Фторопласт-26	МРТУ 6-05-903-63	Для получения пленок, лаковых покрытий и изделий
Фторопластовый уплотнительный материал (ФУМ)	МРТУ 6-М-870-62	Для получения химически стойких и термостойких самонаминающихся прокладочных материалов

Table 31. Selection of compression-molded and semifinished fluoroelastomer materials.

compression-molding (II) and extrusion (III); 7 - Fluoroplast-42 (brands V, P and L); 8 - For making compression-molded and extruded items (P), fibers (V) and lacquer coatings (L), stable in aggressive media; 9 - Semifinished products of fluoroplast-4; 10 - For mechanical fabrication of electrically insulating, antifriction, sealing and chemically stable elements of structures and components; 11 - Intermediate products of waste fluoroplast-4; 12 - For mechanical fabrication of packing and antifriction items; 13 - Sheets of fluoroplast-4; 14 - For gaskets and diaphragms; 15 - Fluoroplast-4 tubing; 16 - For transporting aggressive liquids and gases; 17 - Fluoroplast-3; 18 - In the form of suspensions for anticorrosion coatings and for making plastic articles; 19 - Fluoroplast-3M (brands A and B); 20 - As protective coatings and for making films and plastic articles; 21 - Intermediate products of fluoroplast-3M; 22 - For mechanical fabrication of packing and structural items; 23 - Articles of fluoroplast-3; 24 - As packing elements of structures; 25 - Fluoroplast-26; 26 - For making films, lacquer coatings and plastic articles; 27 - Fluoroplast packing material (FUM); 28 - For making chemically and thermally stable, self-lubricating stuffing and packing materials.

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Many foreign companies produce fluoroplasts under various names: "teflon", "fluon", "hostafion", "fluoroflex", "fluoroplast" and others.

Asbovinyl is a plastic obtained from a mixture of ethinol lacquer and pulverized asbestos. In spite of the fact that it is made by polymerizing divinylacetylene and the tetramer of acetylene, asbovinyl is a thermoreactive plastic, since it transforms into an infusible and insoluble state during the setting process.

Asbovinyl is prepared before using by mixing divinylacetylene lacquer (ethinol lacquer) with asbestos fiber and hardening gradually (for 10-30 days in air without heating or for 2-15 days with heating, depending on the temperature). It can be machined easily<sup>20,24,25</sup>.

Asbovinyl is used for protective coatings and for making sheets, plates, tubing, fittings and other articles<sup>26</sup> which operate in aggressive media: dilute bases, salt solutions, non-oxidizing inorganic and organic acids, dry and wet gases, fresh and salt water. It can be used to protect not only metals, but also wood and concrete.

Recently there has been increasing interest in new chemically-stable thermoplastic materials: polycarbonates, which are products of the reaction of diphenols (for example, diphenylol propane) with esters of carbonic acid or phosgene; polyformaldehyde, produced by polymerizing formaldehyde; and pentoplast, a simple chlorinated polyester (polypentaerythritol). These materials form a special group which, in many respects, destroys the existing notions about thermoplastics. They have a number of valuable properties which make them very suitable for making various items which previously were made of aluminum, copper, bronze, brass, stainless steel and other expensive metals and alloys<sup>27,87</sup>.

The physical and mechanical properties of polycarbonates, polyformaldehyde and pentoplast are listed in Table 32 and data on their chemical stabilities are given in Chapter III.

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Legend for Table 32:

1 - Density, g/cm<sup>3</sup>; 2 - Specific resilience, kgf-cm/cm<sup>2</sup>; 3 - Compression molded; 4 - Limit of strength, kgf/cm<sup>2</sup>; 5 - under tension;

Показатели	Поликарбонаты	Полиформальдегид	Пентопласт
1 Плотность, г/см <sup>3</sup> . . . . .	1,2	1,4	1,4
2 Удельная ударная вязкость, кгс·см/см <sup>2</sup> . . . . .	180—200	30—40 (прессован- ный)	35—40
4 Предел прочности, кгс/см <sup>2</sup>			
5 при растяжении . . . . .	600—890	600—700	420—436
6 при сжатии . . . . .	800—900	1300	900
7 при изгибе . . . . .	800—1000	750—1100	650—770
8 Относительное удлинение при разрыве, % . . . . .	до 85	20—40	25—35
9 Твердость по Бринеллю, кгс/мм <sup>2</sup> . . . . .	15—16	25—40	до 10
10 Теплостойкость по Мартенсу, °C . . . . .	135—140	120	150—170 (по Вика)//
11 Морозостойкость, °C . . . . .	—100	—60	—60
12 Температура плавления, °C . . . . .	235—300	170—180	180
14 Теплопроводность, ккал/м·ч·град . . . . .	0,17	0,308—0,985	—
15 Коэффициент линейного термического расширения, α·10 <sup>6</sup> . . . . .	60—70	1,0*	7,8—8,0
16 Удельное объемное электрическое сопротивление, ом·см . . . . .	4·10 <sup>13</sup> —2·10 <sup>15</sup>	1,2·10 <sup>15</sup>	4·10 <sup>13</sup>
17 Электрическая прочность, кВ/мм . . . . .	100	20—25	23
18 Диэлектрическая проницаемость (при 10 <sup>6</sup> гц) . . . . .	2,6—3,0	3,1—3,2	2,8
19 tg угла диэлектрических потерь (при 10 <sup>6</sup> гц) . . . . .	0,005—0,010	0,003—0,064	0,010
20 Водопоглощение за 24 ч, % . . . . .	0,16—0,3	0,2	0,01

21 \* По зарубежным данным α = (24,7 и 81)·10<sup>-6</sup>.

Table 32. Physical and mechanical properties of polycarbonates, polyformaldehyde and pentoplast.

6 - under compression; 7 - in flexure; 8 - Relative elongation at rupture, %; 9 - Brinell hardness, kgf/mm<sup>2</sup>; 10 - Martens thermal stability, °C; 11 - by Vicat; 12 - Frost resistance, °C; 13 - Melting point, °C; 14 - Thermal conductivity, kcal/m-hr-deg; 15 - Coefficient of linear thermal expansion; 16 - Specific volume electrical resistance, ohm-cm; 17 - Electric strength, v/mm; 18 - Dielectric permeability (at 10<sup>6</sup> hertz); 19 - Tangent of angle of dielectric loss (at 10<sup>6</sup> hertz); 20 - Water absorption in 24 hrs, %; 21 - According to foreign data

Polycarbonates<sup>28,88,89</sup> are thermoplastic polymers, polyesters of carbonic acid, obtained by polycondensation of esters of carbonic acid with bivalent phenols.

Polycarbonates differ favorably from other thermoplastic polymers in their increased strength under impact loading and the stability of their properties and dimensions in a wide range of temperatures from minus 100-135°C to plus 135-140°C. They are resistant to oxidation and to attack by gasoline (with the exception of the lightest), various inorganic, animal and vegetable oils, aliphatic hydrocarbons, alcohols, dilute and fairly concentrated (hydrofluoric, nitric) inorganic and organic acids, and oxidizing and reducing media. They are less resistant to weak bases, amines, ammonia, chlorinated hydrocarbons, pyridine bases and dioxanes<sup>90</sup>.

Along with their high specific resilience, these materials are inherently flexible, so that they retain some elasticity even at temperatures as low as - 190°C.

The mechanical properties of polycarbonates are maintained in air for 26 weeks at 150°C, for 8 weeks at 170°C and for 4 weeks in boiling water. Under normal conditions they absorb 0.3-0.35% moisture at room temperature and not more than 0.58% in boiling water vapor, independently of the time of exposure. This is readily visible in Figure 13.

Polycarbonates have high dielectric properties which are constant over a wide range of temperatures. They can be formed with standard equipment by the methods normally used for thermoplastics: extrusion and pressure-casting. Polycarbonate films and other products can be welded readily by heating or with hot air and can be glued together with cements or appropriate solvents.

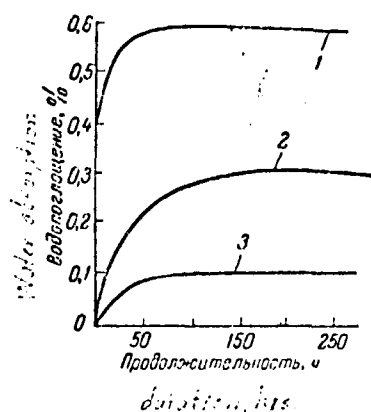


Fig. 13. Stability of polycarbonates in water:

1 - boiling; 2 - under normal conditions; 3 - under conditions of 50% relative humidity.

Polycarbonates can be used in anticorrosion technology as protective coatings, deposited on metallic objects from solutions or by dusting with powder. They can also be used as structural materials for making various containers, tubing, pumps, blower components, stopcocks, fans and other equipment which is in contact with aggressive media.

The polymer is characterized by high transparency, so that it can be used as a high-strength organic glass; moreover, it can be dyed readily in any color.

M. S. Akutin, V. N. Kotrelev, et. al.<sup>29</sup> have made glass plastics based on polycarbonates and glass fabric, having higher mechanical strength than ordinary glass textolites (ST, STU, STK-41).

Polycarbonate (diflon) is manufactured by domestic industry in the form of powder or granules (TU P-262-63).

Polycarbonates are produced abroad under the following tradenames: lexan and merlon (USA), makrolon (FRG).

Polyformaldehyde<sup>10,27,91,92</sup> is a thermoplastic polymer which is produced by polymerizing formaldehyde. It has a linear structure and consists of branched polyoxymethylene chains (. . -OCH<sub>2</sub>-OCH<sub>2</sub>- . .) of great length.

It is characterized by a high degree of crystallinity (about 75%), rigidity, high mechanical and impact strength, elasticity, good modulus of elasticity, high thermal stability and resistance to solvents.

In practice, polyformaldehyde retains its mechanical properties in the temperature interval from - 40 to + 120°C. At these temperatures, even with a loading of 175 kgf/cm<sup>2</sup>, the coefficient of friction of polyformaldehyde on steel (0.1-0.3) does not change, so that it can be used as an antifriction material.

The excellent physico-mechanical properties of polyformaldehyde are combined with good dielectric properties, which gives it great value as an electrically insulating material. According to available information, the physical and dielectric properties of polyformaldehyde remain constant when it is used under conditions of prolonged heating at 85°C and periodically to 120°C, even in the presence of an appreciable amount of moisture or after direct contact with water. The rather high melting point of polyformaldehyde (180°C), along with its high degree of crystallinity and better creep-resistance than other plastics, especially at elevated temperatures, are responsible for the high dimensional stability of objects made of polyformaldehyde.

Figure 14 shows the dependence of the elongation of polyformaldehyde on the duration of application of a constant load at 25°C.

The wear-resistance of polyformaldehyde is higher than other polymeric materials, although not as good as the polyamides. Thus, for example, in

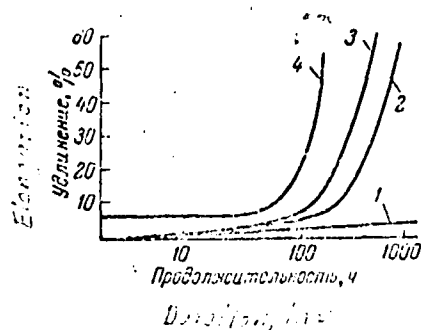


Fig. 14. Dependence of the elongation of polyformaldehyde on the duration of application of a constant load at 25°C (in kgf/cm<sup>2</sup>):

1 - 350; 2 - 434; 3 - 455; 4 - 490.

abrasion tests using a ball mill, the relative loss of mass (in g) of polyformaldehyde and other materials amounted to:

Material	Loss of mass, g
Polyamides . . . . .	1
Polyformaldehyde . . . . .	4-6
Polystyrene . . . . .	15-20
Hard rubber . . . . .	10
Steel . . . . .	15-20

Polyformaldehyde is characterized by increased resistance (compared, for example, with polyethylene) to the action of organic solvents: alcohols, esters, and especially aromatic, aliphatic and halogen-containing hydrocarbons. However, it decomposes in concentrated inorganic acids and bases and is less resistant to water than polyethylene. For more detailed information on the chemical stability of polyformaldehyde, see Chapter III.

Polyformaldehyde can be formed easily with standard equipment by the ordinary methods: casting, extrusion and compression-molding. It can be welded and cemented easily.



The extrusion method can be used to form polyformaldehyde into various items of fixed cross section: bars, hoses, rods, tubing. It can also be used as a structural material for making gears, bearings of sliding collars, fittings and other items. Polyformaldehyde film is very strong and withstands protracted loading. It is also resistant to ordinary solvents. Polyformaldehyde with added stabilizers is produced in the form of a powder or granules of two brands: A - casting, B - extrusion, of various designations (STU 36-13-8--64).

Polyformaldehyde is manufactured abroad by the Duport company under the name "delrin".

Pentoplast<sup>5,10,27,93</sup> is a thermoplastic polyester, chlorinated polypenterythritol. It is a crystalline polymer and the chloromethyl group is bound to a carbon atom of the primary chain of the polymer. Pentoplast contains up to 46% chlorine. In contrast to polyvinyl chloride and perchlorovinyl, it does not evolve hydrogen chloride when it is heated to 285 °C, and this guarantees good chemical stability of the material.

Pentoplast is resistant to most organic solvents, weak and strong bases, and weak and fairly strong acids. It is affected only by strongly oxidizing acids, such as nitric and fuming sulfuric.

Under the influence of aggressive media, the mechanical properties of pentoplast change to an appreciably smaller degree than do those of fluoroplast-3. Pentoplast is more resistant than polypropylene to concentrated inorganic acids (30% chromic and 60% sulfuric), organic acids (75% acetic) and especially organic solvents: ketones, chlorine-containing hydrocarbons and aromatic hydrocarbons. This increased chemical stability of pentoplast is due to its structure -- the strength of the bonds between the chloromethyl

groups and the carbon atoms of the primary chain and the compactness of its crystal structure. The fortunate combination of physico-mechanical properties with increased chemical stability distinguishes pentoplast favorably from other thermoplastic materials. Pentoplast also maintains its valuable combination of mechanical characteristics and dimensional stability at elevated temperatures. Its thermal stability is greater than ordinary thermoplastics -- even fluoroplast-3, to which it is comparable in chemical stability. Thus the diameter of a specimen of pentoplast which is held at 40°C for 24 hours changes by approximately 0.05 mm, and at 80°C it changes by 0.06 mm. Under the same conditions, the diameter of a specimen of fluoroplast-3 changes by 0.53 and 0.57 mm, respectively; that is, 10 times as much. In practice, pentoplast can be used at 120-125°C and, in the opinion of some investigators, at temperatures up to 150°C.

On the basis of its dielectric properties, pentoplast occupies an intermediate position between polyethylene or polystyrene (with small coefficients of dielectric loss) and polyamides.

Pentoplast has good engineering properties: it is easily welded with hot air and it has sufficiently low viscosity at the melting point (about 180°C). Its volume does not change appreciably during the transition from the molten to the solid state, and therefore the dimensions of pentoplast items are maintained during cooling and no internal stresses are set up. Pentoplast can be formed readily by pressure-casting or extrusion with ordinary equipment; films obtained by the extrusion method have good mechanical characteristics.

Pentoplast is used as a corrosion-resistant structural material and as a protective coating<sup>87,94</sup>. Pentoplast coatings can be applied by the method

of gas-flame dusting, dipping in a suspension of the polymer, or atomization with subsequent sintering of the powder. Sheet pentoplast can be used for protective linings. Pentoplast can be used to make equipment which operates at high temperatures in aggressive media: valves and fittings, components of pumps, valve diaphragms, tubing, packing, etc. Pentoplast is well-known abroad under the name "penton" and is used widely in the chemical industry for making piping systems, ventilation ducts, distillation columns, scrubbers and reactors. Tubing of low-alloy steel is covered with a layer of penton 0.8-1.0 mm thick. The Hercules Powder Co. manufactures such tubing in lengths of 3.5 m with diameters from 40 to 600 mm.

Chlorinated polypentaerythritol is also manufactured under the tradename "perodlon 301" in the form of an aqueous suspension which is used to cover centrifuges (the suspension is characterized by excellent adhesion to metal).

#### Polycondensation Plastics

Reinforced polycondensation thermoreactive plastics, containing fillers, are characterized by high strength and are used as structural materials. Polycondensation plastics filled with glass fiber, glass fabric or other forms of glass material are so strong and light that they can be used for the fabrication of large-scale objects, such as the hulls of boats and ships, automobile bodies, and even buildings.

The properties of polycondensation plastics which are used as corrosion-resistant materials are shown in Table 33.

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Legend for Table 33:

A - Principal characteristics; B - Phenoplasts; C - Phenolites (K-17-20, K-18-23 and others); D - Faolite; E - Textolite; F - Amonoplasts A & B;

A Основные показатели	Б Феноляты			F Аминопласти А и Б	G Полиамид	H Полиэфирные сколы	I Крепленоргани- ческие сколы (асбестопласти)	J Эпоксидные сколы (отверж- денные)
	Феноляты (К-17-23 и др.)	Ф	Е текстолит					
/ Исходные мономеры . . . . .	$C_6H_5OH$ и $CH_2O$			$CO(NH_2)_2$ и $CH_2O$	2 Диамин, глино- и дикарбон- овые кисло- ты, лактам	3 Дикарбон- овые кисло- ты или их ангидриды и гликоли	$R-O-Si-OH$   R	4 Эпоксидные соединения (эпихлор- гидрин) и двух- атомные фенолы
5 ГОСТ или технические усло- вия . . . . .	ГОСТ 5689-60 1,6	ТУ ГХП 35-44 1,6	ГОСТ 5-52 1,3-1,4	ГОСТ 9359-60 1,4-1,5	ТУ М 617-57 1,11	ВТУ ЛСНХ 33024-59 1,6-1,7	ВТУ МХП 4386-55 1,9	См. стр. 106 1,2-1,23
6 Плотность, $g/cm^3$ . . . . .	4,5-7,0	3,5-5,5	25-35	5-6	100-120	250-300	18-20	15-20
7 Удельная ударная вязкость, $кгс/см^2$ . . . . .	300-400 1500-1700 550	150-350 500-900 300-600	860-1000 2300-2500 1200-1600	500-600 1500 600-800	450-600 700-800 800-900	2700-3000 2100-3500 1900-2700	230-600 1325 500-800	700-800 1300-1600 1200-1300
8 Предел прочности, $кгс/см^2$ . . . . .	—	0,2	0,8-1	0,2-0,5	100	5	—	—
9 при растяжении . . . . .	30-40	20	35	30	14-15	—	20	10-12
10 при сжатии . . . . .	125	150	125	100	60	92-200	260-350	105-110
11 при изгибе . . . . .	1,1	0,7-1	5-8,2	9	8	4	—	—
12 Относительное удлинение при разрыве, % . . . . .	—	2-2,5	3,5-4,0	2,5-5,5	11-12	8-10	—	6
13 Твердость по Бринеллю, $кгс/мм^2$ . . . . .	5,10 <sup>12</sup> -5,10 <sup>13</sup>	10 <sup>8</sup>	10 <sup>10</sup> -10 <sup>12</sup>	10 <sup>11</sup>	4,5,10 <sup>12</sup>	10 <sup>14</sup> -10 <sup>15</sup>	10 <sup>10</sup>	10 <sup>14</sup>
14 Теплостойкость по Мартенсу, °C . . . . .	14,3-18	—	5	10-15	15-30	20	2	25-30
15 Теплопроводность $\lambda \times 10^4$ $кал/см \cdot сек \cdot град$ . . . . .	—	—	8	5-7	3,8-4,2	3,0-4,3	—	3,6-3,9
16 Коэффициент линейного термического расширения $\alpha \times 10^{-5}$ . . . . .	—	—	—	0,07	0,025-0,03	0,020	0,01-0,04	0,003
17 Удельное объемное электри- ческое сопротивление, ом-см . . . . .	0,02-0,04 (при 10 <sup>4</sup> гц)	—	0,2-0,4	0,5-0,7	0,5*	0,3-0,5	0,2-0,5	0,3
18 Электрическая прочность, ка/мм . . . . .	140	120-160	100-120	—	100	—	200-300	120
19 Диэлектрическая проницае- мость (при 50 гц) . . . . .	—	—	—	—	—	—	—	—
20 tg угла диэлектрических по- тери (при 50 гц) . . . . .	—	—	—	—	—	—	—	—
21 Водопоглощение за 24 ч, % . . . . .	—	—	—	—	—	—	—	—
22 Температурный предел приме- нения, °C . . . . .	—	—	—	—	—	—	—	—

Table 33. Physical and mechanical properties of polycondensation plastics.

Legend for Table 33 (con't):

- G - Polyamides; H - Polyester resins; I - Organosilicon resins (asbovoloknite); J - Epoxide resins (reinforced);
- 1 - Original monomers; 2 - Diamines, amino- and dicarboxylic acids, lactams; 3 - Dicarboxylic acids or their anhydrides and glycols;
- 4 - Epoxide compounds (epichlorohydrin) and diatomic phenols; 5 - GOST or technical conditions; 6 - Density,  $\text{g/cm}^3$ ; 7 - Specific resilience,  $\text{kgf/cm}^2$ ; 8 - Limit of strength,  $\text{kgf/cm}^2$ ; 9 - under tension; 10 - under compression; 11 - in flexure; 12 - Relative elongation at rupture, %;
- 13 - Brinnell hardness,  $\text{kgf/mm}^2$ ; 14 - Martens thermal stability,  $^{\circ}\text{C}$ ;
- 15 - Thermal conductivity,  $\text{cal/cm-sec-deg}$ ; 16 - Coefficient of linear thermal expansion; 17 - Specific volume electrical resistance,  $\text{ohm-cm}$ ;
- 18 - Electric strength,  $\text{kv/mm}$ ; 19 - Dielectric permeability (at 50 hertz); 20 - Tangent of angle of dielectric loss (at 50 hertz);
- 21 - Water absorption in 24 hrs, %; 22 - Temperature limit of utilization,  $^{\circ}\text{C}$ .
- 23 - According to data quoted in the book "New Materials in Engineering" (Novye materialy v tekhnike), edited by E. B. Trostyanskaya, Gostoptekhzdat, 1962, p. 51, the water capacity of polyamide 68 is from 2.5 to 8-10%.
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Phenoplasts are the most familiar thermoplastic plastics, based on phenol-formaldehyde resins. They are products of the polycondensation of phenol with formaldehyde.

They are divided into three categories, depending on the nature of the filler: pressing-powders, fiberites and textolites. The largest group is composed of the pressing-powders, which are formed into objects by ordinary

casting or forming methods. Pressing-powders are classified as general purpose, with good electrically-insulating properties, increased water-stability and high heat-resistance (K-18-36, K-211-2 and others); chemically stable (phenolites and decorrozites); high-strength (FKP, FKPM); and special-purpose (for semiconductors and components of X-ray apparatus, K-104-205).

In anticorrosion engineering, fiberite and the laminated plastics, faolite and textolite<sup>10,25</sup>, are much more valuable than pressing-powders.

Fiberite (voloknit) (TU MKhM 459-57) is used to make items with increased mechanical strength. Glass fiberite AG-4 (GOST 10087-62) is used for objects which must withstand high temperatures (temperature limit of use, from - 60 to + 200°C; Martens thermal stability, 280°C). Glass fiberite AG-4 is formed into articles by hot-pressing. The limit of strength amounts to 5000 kgf/cm<sup>2</sup> under tension and 1300 kgf/cm<sup>2</sup> under compression. A typical representative of the fiberites used as anticorrosion materials is faolite, a thermoreactive plastic based on a resol phenol-formaldehyde resin. The fillers used are asbestos (brand A), asbestos and graphite (brand T) or asbestos and quartz sand (brand P).

In the reinforced state, faolite is characterized by high chemical stability, strength and machineability. It is manufactured in the crude form (for coatings, linings, or as putty) and in the reinforced state in the form of sheets and finished items. Faolite hardens at 120-130°C.

The selection of finished and semifinished products of faolite is shown below:

Crude faolite sheets, 1000 x 1400 mm, 8-20 mm thick,  
brands A and T

TU MKhP 322-45

Reinforced faolite sheets of the same dimensions,  
brands A and T

TU GKhp 35-44

Faolite putty, brands A and T	TU MKhP 34-44
Faolite pipe and fittings of diameter up to 200 mm, brands A and T	TU MKhP 321-45
Valves for tubing of diameter 50 and 100 mm	TU MKhP 325-51
Stopcocks for tubing of diameter 33 and 50 mm	TU MKhP 325-51
Vats with capacity from 60 to 1400 liters	TU MKhP 324-45
Adsorption towers, plate and cap columns, tubular absorbers, coolers, centrifugal pumps and other equipment	TU MKhP 3014-51

Faolite is known abroad under the name "Ilaveg".

Textolites and glass textolites are materials based on phenol-formaldehyde resins which are impregnated with cotton or glass fabrics. They are used as structural materials for making antifriction and electrically insulating items, and also components which operate in aggressive media.

The following kinds of textolite are available, depending on the application: small pieces (GOST 5-52), sheet electrotechnical (GOST 2910-54), metallurgical (GOST 4164-54) and textolite rods (GOST 5385-50). The first of these is used as a corrosion-resistant material.

Aminoplasts are thermoreactive plastics based on carbamide resins, products of the polycondensation of formaldehyde with urea and its derivatives. The most widely used of them are pressing-powders of various colors, brands A and B, K-77-51 (TU M-3683-53) and others, used for arc-resistant electrotechnical components and other items.

Polyamides<sup>30</sup> are products of the polycondensation of aminocarboxylic acids or diamines with dicarboxylic acids, or of the stepwise polymerization of lactams. They are manufactured primarily as polymers which are formed by pressure-casting or compression-molding. They are used to fabricate various

items for machine-construction, electrical, aviation and other industries, and also films and cements. Appreciable amounts of polyamides are used to make synthetic fibers.

Examples of polyamides used as plastics are nylons, capron, caprolon, resin 68, etc. Table 34 lists the brands and purposes of polyamides manufactured by domestic industries. They are distinguished by high wear- and abrasion-resistance, good antifriction properties, and resistance to atmospheric effects, water and many chemical reagents.

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Legend for Table 34:

1 - Polyamide resin 54; 2 - For shock-resistant items which are not affected by petroleum products, oils, ethers and bases; 3 - Polyamide resin 548; 4 - Same; 5 - Polyamide resin 68; 6 - For items which are resistant to shock, mechanical effects, aliphatic-, aromatic- and chlorinated hydrocarbons, alcohols, aldehydes, ketones and solutions of bases; 7 - Polyamide resin AK-7; 8 - For water-, oil- and gasoline-resistant articles with good dielectric properties; 9 - Caprolon; 10 - For large-scale items, gears, bushings, sleeves, washers, packing materials; 11 - Polyamide film PK-4; 12 - For sealing and insulating materials which are stable to hydrocarbons, and for packing and gas-impermeable materials; 13 - Capron (polycaprolactam); 14 - For gears, bushings and parts of armatures; 15 - Reinforced polyamide 68; 16 - For antifriction items which are resistant to water, bases, benzene and gasoline.

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Polyester resins are products of the condensation of polyatomic alcohols and dibasic acids or anhydrides (so-called alkyd resins).



Наименование и марка	ТУ ГОСТ или ТУ	Назначение
1 Полнаммидная смола 54	ТУ МХП М 318—56	В качестве ударопрочных изделий, стойких к действию нефтепродуктов, масел, эфиров и щелочей
3 Полнаммидная смола 548	ТУ М 739—57	То же
5 Полнаммидная смола 68	ТУ М 617—57 ГОСТ 10589—63	В качестве механических и ударопрочных изделий, стойких к алифатическим, ароматическим, хлорированным углеводородам, спиртам, альдегидам, кетонам, маслам и растворам щелочей
7 Полнаммидная смола АК-7	ВТУ П328—63	В качестве водомаслобензостойких изделий с хорошими диэлектрическими свойствами
9 Капролон	ТУ П382—64	Крупногабаритные изделия, шестерни, вкладыши подшипников, втулки, кольца, уплотнительные прокладки
11 Полнаммидная пленка ПК-4	ТУ УХП МОСНХ 17—58	В качестве герметизирующих изоляционных материалов, стойких к углеводородам, упаковочного и газонепроницаемого материалов
13 Капрол (поликапролактан)	ВТУ ГХП М 687—57	В качестве шестерен, вкладышей подшипников, деталей арматуры
15 Наполненный полиамид 68	ВТУ УХП 69—58 ВТУ П179—60 ТУ П323—63	В качестве антифрикционных деталей, водо-, щелоче-, бензоло- и бензиностойких

Table 34. Selection and purpose of polyamides.

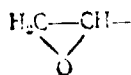
When polyesters are made from acids and alcohols containing reactive double bonds between the carbon atoms, the polymers formed are unsaturated polyester resins. They are used as binders in structural glass-plastics, and also as colored-lacquer materials and cements<sup>31</sup>. Domestic industries produce polyester resins of the following brands: PN-1 (STU 30-14086-63), PN-3 (STU 30-14263-64), TGM-3 and MGF-9 (VТУ BU17-56), THGF-11 (STU 12-10111--61).

Organosilicon polymers are products of the polycondensation of alkylhydroxysilanes (organosilicon compounds). The polymer chains of these molecules consist of alternating silicon and oxygen atoms, and the silicon atoms

are bonded to various organic radicals. The transformation of the resins to the thermostable state occurs at 160-200°C. The products obtained have good mechanical strength (nearly constant over a wide range of temperatures from -50 to +300-350°C) and high dielectric properties. Organosilicon polymers are used to make lacquers, impregnating compositions, cements and plastics; also rubbers and liquids for lubricating oils, heat-transfer fluids and hydrophobic materials.

The addition of a filler to an organosilicon polymer yields a high-strength, thermostable, electrically-insulating material which is used to make electrical equipment and fittings, casings and components of electrical and radio instruments, arc-resistant items and various small articles which operate under conditions of elevated (up to 200-300°C) temperatures. At the present time, the following organosilicon plastics are being manufactured: asbofiberite K-41-5 TU 35-XII-572-63, compression-molding materials of various brands and glass textolites SKM-1 TU OEPP503-001--57 and STK-41 TU 35-EP-270-64 STK-71 VTU 76--58.

Epoxide resins (polyoxyesters) are oligomers and polymers whose macromolecules contain epoxide groups



They are produced by polymerizing diatomic phenols with epoxide compounds (epichlorohydrin). The epoxide groups are located at the ends of the chain and the hydroxyls are distributed along the entire chain. They harden under the influence of amines, anhydrides of dibasic acids and other reagents by the mechanism of the polycondensation reaction. The hardening process takes place not only with heating, but also at room temperature. Various brands of

epoxide resins are produced, depending on the number of epoxide groups and the molecular weight. They are liquids of a variety of viscosities or solids.

Epoxide resins adhere very well to metals, glass and other nonmetallic materials, including plastics. They have high mechanical strength, good dielectric properties, and chemical stability in acid and basic media.

Epoxide resins are used to make cements, lacquers, enamels, patching and sealing compounds, and electrical and radio components. They are also used as binders for glass plastics and other laminated materials, as well as for protective coatings<sup>32</sup>.

The following brands of epoxide resins are manufactured by domestic industries: ED-5, ED-6, ED-L and ED-P (GOST 10587-63), E-40 (TU UKhP-295--55) and E-37 (STU 30-14118--63).

Also available are the epoxide compounds K-153 (STU 30-14161--64) for cementing materials and K-115 (STU 30-14148--63) for impregnating, sealing and cementing of materials, etc.

#### Bituminous-asphaltic Plastics

This group includes plastics based on natural and petroleum asphalts and resins, bitumens, coal-tars, shale- and ligneous pitches. They are obtained by the pyrogenic destruction of various organic substances.

Plastics of this type are resistant to mineral acids (weak and fairly concentrated) and solutions of salts and bases. They are used chiefly for insulation and corrosion-protection of underground pipelines and mains. They are also used for the protection of floors in chemical plants<sup>33</sup>.

Petroleum bitumens are used in the form of primer compositions (solutions of bitumen in gasoline), as the primary material of coatings, and also for gluing roofing-paper materials. Several brands of petroleum bitumens are available, depending on the softening temperature and other properties.

Thermoplastic asphalt-pitch material (TU GKhp 26-50) is used for the compression-molding of battery casings, lids and plugs.

Bituminous mastics (bituminoils) are obtained by fusing bitumens with mineral-acid-resistant fillers (cements, kaolins, diabasic and andesitic flours, etc.) and with reinforcing additives (asbestos). Good results are also obtained by adding 5-10% rubber (in the form of crumbs) to the bitumen. This improves the elasticity, frost-resistance, stability of electrical resistance in electrolyte solutions, mechanical strength and other properties of the bitumens.

Bituminous-rubber mastics of brands MBR-I-90, with softening temperature not less than 90°C, and MBR-13-80, with softening temperature not less than 80°C, are used for insulating work.

Mastic compositions frequently include rubrax, which is a high-melting elastic product obtained by special processing of bitumens. A waterproof roofing-paper material based on bituminous-rubber mixtures is known by the name brisol. Sheet roofing cardboard impregnated with bitumen is known as hydroisol; a mixture of bitumen and asbestos fiber, processed on rollers and calenders, is called borulin.

Bituminous materials mix well with synthetic resins. Thus, for example, adding epoxide resin to coal-tar resin yields the valuable anticorrosion material EKS-1, which combines the properties of both constituents. This material is applied in the form of a mastic, and it sets without heating in

layers of any thickness. Coatings of EKS-1 are stable in sulfuric, hydrochloric and 5% nitric acids, and also in bases, petroleum products, oils and gasoline.

#### Materials Based on Rubbers

Natural and synthetic rubbers are high-molecular-weight compounds designed for making elastic and rubber objects. Synthetic rubber is usually made by polymerization and copolymerization of various unsaturated compounds. Some rubbers are produced by the polycondensation of appropriate bifunctional hydrocarbon derivatives. Rubbers are normally used in mixtures with other ingredients: fillers, vulcanizing agents, plasticizers, stabilizers and aging-retardants. In the vulcanization of rubber with sulfur, for example, the agent adds at the sites of double bonds and "sews" the material together. That is, a three-dimensional macromolecular structure is formed, giving the rubber strength, elasticity and a certain rigidity. Depending upon the amount of sulfur introduced into the mixture, it is possible to obtain rubbers which are soft (2-4 parts sulfur to 100 parts rubber by weight), semirigid and rigid, called ebonites (50-60 parts sulfur to 100 parts rubber by weight). Ebonite can be used independently for the protection of equipment or as a sublayer, but it can also be used as a structural material. Domestic industries produce ebonite sheets (GOST 2748-53), pipe (TU MKHP 1420-47) and tubing (TU MKHP 26-11).

Rubbers are used not only to obtain resins and ebonites, used as corrosion-resistant packing and sealing materials and for rubberizing (that is, the coating of equipment to protect it from the action of aggressive media), but also for making cements, colored-lacquer materials, sealants, binders, etc<sup>34</sup>. Figure 15 shows the classification of rubbers used in anticorrosion

technology.

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Legend for Fig. 15:

1 - Rubbers; 2 - Synthetic; 3 - Natural; 4 - Special-purpose rubbers;  
5 - General-purpose rubbers: SKB (sodium-butadiene), SKS (butadiene-styrene), SKD (cis-butadiene), SKI (isoprene); 6 - Thermostable: SKT (silicone) and thermooenzostable: SKF (fluorinated rubbers), SKTF (fluoro-silicones); 7 - Wear-resistant: SKU (polyurethanes); 8 - Gas-tight: butyl rubber; 9 - Frost-resistant: SKS-10, SKMS-10 (butadiene-styrene and  $\alpha$ -methyl styrene), SKD (cis-butadiene), SRM (butadiene, obtained by catalytic polymerization); 10 - Gasoline- and oil-resistant: SKN (butadiene-nitrile), polysulfides (thiokols), chloroprenes (nyrite), NVP (methylvinylpyridinyl); 11 - Chemically-stable and ozone-resistant: polyisobutylene, butyl rubber, chlorosulfonated polyethylene, fluororubbers, chloroprenes.

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Large amounts of rubber are used for making tires. Smaller amounts are used for making industrial rubber items and relatively small amounts are manufactured in the form of commercial non-vulcanized rubbers, some of which are intended for rubberizing.

Synthetic rubbers of the following kinds are produced in the Soviet Union: sodium-butadiene (SKB), which is gradually being replaced by the more satisfactory polybutadiene of regular structure (SKD); butadiene-styrene (SKS and SKMS); butadiene-nitrile (SKN); polychloroprene (nyrite); polysulfide (thiokols); silicone (SKT) and several special types of rubbers. Almost all of the rubbers listed above are used to prepare rubberizing resins, ebonites and sealants. At the present time, natural rubber (NR) is still being used

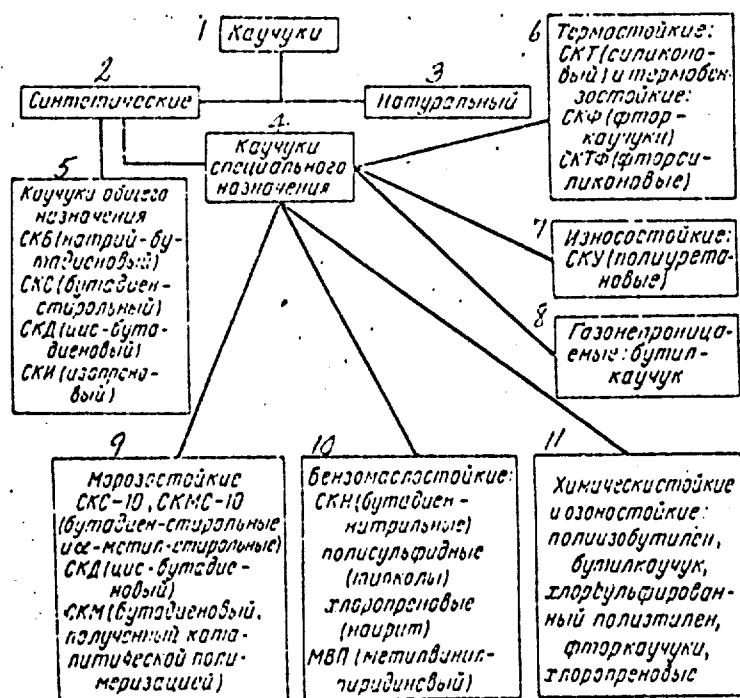


Fig. 15. Classification of rubbers according to properties and purpose.

to an appreciable extent for rubberizing resins. Its structure is that of polyisoprene<sup>35-38</sup>. Synthetic polyisoprene rubber (SKI), analogous to natural rubber, has now been made and is being accepted. It can replace natural rubber successfully in rubberizing resins<sup>39</sup> (see Table 35).

#### Legend for Table 35:

- 1 - Aggressive medium and test conditions; 2 - Physico-mechanical characteristics; 3 - Resins based on SKI-3, with filler of; 4 - powdered silica gel; 5 - lamp black; 6 - Resins based on NK, with filler of; 7 - 20% hydrochloric acid, 65°C, 25 days; 8 - Strength; 9 - Relative elongation; 10 - Swelling; 11 - 33% sulfuric acid, 65°C, 50 days; 12 - 20% acetic acid, 50°C, 50 days.

1 Агрессивная среда и условия испытаний	2 Физико-механические показатели	Резины на ос- нове СКН-3, наполненные		Резины на ос- нове НК, наполненные	
		белой сажей	ламино- вой сажей	белой сажей	ламино- вой сажей
I 20%-ная соляная кис- лота, 65°C, 25 суток	Прочность	-7	-59	-34	-30
	Относительное уд- линение	-8	-68	+10	-22
	Набухание	+3,7	+22,2	+4,1	+16,1
II 33%-ная серная кисло- та, 65°C, 50 суток	Прочность	-5,5	-25,5	-23,6	-2,0
	Относительное уд- линение	-7,5	-67,0	+9,0	-3,0
	Набухание	+7,1	0,0	+7,7	+0,51
III 20%-ная уксусная кис- лота 50°C, 50 суток	Прочность	-19	-48	-27	-53
	Относительное уд- линение	0,0	-45	+1,5	-10
	Набухание	-0,7	+24,0	+5,9	+38,1

Table 35. Relative change of physico-mechanical characteristics of resins based on SKI-3 and NK in aggressive media (in %).

Non-vulcanized commercial rubbers are divided into two basic groups, in accordance with the purpose and operating conditions: general industrial and special purpose. The group of rubbers of general industrial purposes consists of soft rubbers, as well as those of medium and high rigidity. It includes: 1) rubbers designed for protection from water, air and weak solutions of acids and bases; 2) thermostable rubbers; 3) frost-resistant rubbers; 4) oil- and gasoline-resistant rubbers and 5) rubbers with increased oil- and gasoline resistance. Special-purpose rubbers include those used for the rubberizing of chemical equipment and for the coating of drums and fittings.

In selecting rubbers and ebonites for protection from the action of aggressive media, it is expedient to use the data of the All-Union Scientific Research Institute for Standardization and Machine-Construction (VNIISASH), RTM 22-61, "Protective Coatings by Rubberizing"<sup>49</sup>.

The physical and mechanical properties of the rubbers and ebonites most widely used for rubberizing, together with the methods used to bond them to



metals, are listed in Table 36.

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Legend for Table 36:

A - Brand; B - Basis (rubber); C - Density,  $\text{g/cm}^3$ ; D - Limit of strength,  $\text{kgf/cm}^2$ ; E - under tension, not less than; F - in flexure; G - Elongation, %; H - relative, not less than; I - residual, not more than; J - Rigidity by TM-2,  $\text{kgf/cm}^2$ , GOST 263-53; K - Williams plasticity; L - Frost-resistance,  $^{\circ}\text{C}$ ; M - Method of bonding to metal.

1 - Rubberizing (soft) resins; 2 - With thermoprene cement and 4508; 3 - By means of a sublayer of ebonite or thermoprene cement; 4 - By means of a sublayer of ebonite; 5 - With leuconate or 200 cement; 6 - Standard recipe; 7 - Nyrile; 8 - Butyl rubber; 9 - Semiebonites; 10 - With cements 2572 and 1805; 11 - Ebonites.

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In addition to rubberizing resins, rubber lining-, packing- and sealing materials are also used in anticorrosion technology. Linings are made from industrial sheet rubber (GOST 7338-55) of five types: acid-base-resistant, thermostable, frost-resistant, oil-gasoline-resistant of brands A, B and V, and sanitary (for foodstuffs).

The physical and mechanical properties of industrial sheet rubbers are shown in Table 37 (the first number of each entry refers to soft rubber and the second to hard rubber).

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Legend for Table 37:

1 - Type of rubber; 2 - Limit of strength under tension,  $\text{kgf/cm}^2$ ; 3 - Elongation, %; 4 - relative; 5 - residual; 6 - Rigidity by TSM-2,  $\text{kgf/cm}^2$ ; 7 - Acid-base-resistant; 8 - Thermostable; 9 - Frost-resistant;

А Марка	В Основа (каучук)	С Плотность, г/см <sup>3</sup>	D Прочность кгс/см <sup>2</sup>		E Удлинение, %		J Твердость по ТМ-2 кгс/см <sup>2</sup> ГОСТ 263-53	K Пластич- ность по Вильямсу	L Моро- зостой- кость °C	M Способ крепления к металлу
			F при растя- жении не ме- нее	F при изгибе	E при растя- жении не ме- нее	E при изгибе				
I Гум. резины (масса) резины										
829	NK СКБ HK+СКБ	1,06	160	—	650	30	40—50	—	—45	Клеем терморен и 4508 2
1976	СКБ	1,14	60	—	225	20	56	—	—40	С помощью подслоя эбо- нита или клеем терморен 3
2566	NK+СКБ	1,1—1,2	150	—	600	35	20—40	—	—40	Клеем терморен и 4508 2
4476	СКБ	1,15	55	—	150	15	52	—	—40	С помощью подслоя эбо- нита или клеем терморен 3
4849	NK	1,39	180	—	550	40	31	—	—50	С помощью подслоя эбо- нита 4
8ЛТИ ЛТИ	5A3 СКБ-30	1,06	240	—	570	20	65—75	—	—50	Клеем лейконат или клеем 200 5
343	5A115 СКМС-50	1,14	90	—	280—300	25	60—80	—	—60	То же 5
8583	СКБ-30	—	40	—	200	40	55—75	—	—30	»
Стандарт- ный рецепт ИРП	5A11 СКП-40	—	90— 100	—	300—500	10—30	40—85	—	—50	»
	ИРП-1025	7 Наирит	1,48	100	—	361	8	84	—	—
ИРП-1255	3 Бутил- каучук	1,25	~150	—	500	15—60	—	—	—40	»
II Полуэбониты										
1751	СКБ	1,32	274	638	—	—	—	3,0—4,5	—	Клеем 2572 и 1805 1,3
1726	NK	1,12	—	940	—	—	—	—	—	То же 5
III Эбониты										
1814	СКБ	1,33	361	713	—	—	—	4,0—5,5	—	»
2109	СКБ	1,21	320	577	—	—	—	3,5—5,0	—	»
2160	СКБ	1,14	450	890	—	—	—	3,0—4,0	—	»

Table 36. Physical and mechanical properties of soft rubbers and ebonites used for rubberizing.

10 - Oil-gasoline-resistant, of brands; 11 - Sanitary.

1 Тип резины	2 Предел прочности при растяжении кгс/см <sup>2</sup>	3 Удлинение, %		6 Твердость по ТШМ-2 кгс/см <sup>2</sup>
		4 относительное	5 остаточное	
7 Кислотощелочестойкая . . . . .	35—55	350—200	25—20	4—20
8 Теплостойкая . . . . .	40—60	300—100	18—15	4,5—26
9 Морозостойкая . . . . .	40—65	250—200	25—20	4—20
10 Масло-бензостойкая марок:				
А А . . . . .	60—95	250—200	30—20	4—21
В В . . . . .	45—55	400—180	40—15	4—22
У В . . . . .	45	150	15	10—12
11 Пищевая . . . . .	40—45	350—300	35—20	4—10

Table 37. Physico-mechanical properties of industrial sheet rubbers.

Sealing materials are most often prepared in the form of mastics or pastes. For the most part, they do not require heating for vulcanization or hardening. Sealants are made from polysulfide rubbers (thiokols), silicones, butadiene-nitrile rubbers combined with resins, and certain special fluorine-containing rubbers.

Two brands of thiokol sealants are produced: U-30M (TU UT-949--58) and UT-3i (VTU UT-932--59). These materials are made up of three components, which are mixed before use: the first component is the paste U-30 (thiokol filled with carbon black or titanium white), the second is the paste P-9, containing a vulcanization agent and a plasticizer, and the third is a vulcanization accelerator in the form of a powder<sup>41</sup>.

For better adhesion, thiokol sealants are not applied directly to the metal, but on a primer (VTUR, cements 8С-II, K-50, etc.). The vulcanization of thiokol sealants takes place at room temperature in an average time of 24 hrs. Besides their primary purpose (sealing materials), thiokol compounds may be used as coatings to protect metals from moisture and water vapor,

gasoline, solutions of inorganic acids and their salts, and from atmospheric and other influences. The adhesion of thiokol sealants and some of their properties are improved by combining them with epoxide resins.

Electrically-insulating sealing compounds based on silicone rubbers have been developed for protection from the action of moisture and the atmosphere in a wide range of temperatures from -60 to +300°C. The most useful and familiar industrial silicone sealant is the compound KL (VTU V-16--64).

The sealants GEN-150 (TU P-105--58) and GEN-301 (VTU MKhP 3284--52) are mixtures of butadiene-nitrile rubber SKN-40 with phenol-formaldehyde resins (bakelite resin VDU and resin FKF). They are 5-6 times stronger than thiokol sealants and 10-20 times stronger than silicones. Their adhesion to steel is not less than 35 kgf/cm<sup>2</sup>, and to aluminum it is as high as 70-170 kgf/cm<sup>2</sup>.

#### New Types of Elastomers

The new elastomers which are used for protection from corrosion are subjected to more rigorous demands for chemical stability and resistance to abrasive wear, erosion, ageing in oxidizing media, etc. Elastomers based on chlorosulfonated polyethylene, fluorine-containing polymers and copolymers, and polyurethane rubbers<sup>95</sup> have such properties in some degree.

Chlorosulfonated polyethylene (KhSPE) is obtained as a result of the introduction of a sulfochloride group (SO<sub>2</sub>Cl) into the polyethylene molecule in a preparation of polyethylene dissolved in carbon tetrachloride, sulfonyl chloride (SO<sub>2</sub>Cl<sub>2</sub>) or a mixture of chlorine and sulfur dioxide. The rubber-like polymer, obtained in the form of white friable crumbs, is vulcanized by metal oxides or salts of organic acids (chiefly magnesium oxide and lead oxide or lead salts of organic acids). The structurization occurs as a result of

hydrolysis and subsequent reaction with sulfochloride groups. Vulcanization occurs in the presence of organic acids or colophony (hydrogenated), which improves the strength and engineering properties of the mixtures<sup>42,43</sup>.

Compared with other rubbers, KhSPE vulcanized rubbers are characterized by exceptional properties: ozone-resistance, resistance to abrasion and repeated bending, thermal stability (up to 120°C), and high stability in water, strong oxidizers, solutions of acids and bases, and salts of inorganic acids. Like rubbers based on NK, their brittleness temperature amounts to 40°C.

The recipes of rubber mixtures based on KhSPE are given in Table 38, and Table 39 lists the properties of the vulcanized rubbers (see Chapter III for data on chemical stability). These materials are used for rubberizing tanks, pipe, voltaic cells and other equipment; they are also used for linings, acid-resistant hoses, valve linings, and bearings for pumps and other machinery. KhSPE is being produced on a pilot-plant scale. It has been manufactured abroad for more than 10 years under the name "hypalon"<sup>96</sup>.

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Legend for Table 38:

1 - Polymer (KhSPE); 2 - Hydrogenated colophony; 3 - Lampblack or channel black; 4 - Precipitated chalk; 5 - Magnesium oxide; 6 - Lead oxide; 7 - Thiuram; 8 - Altax; 9 - Captax; 10 - Neozone D.

---

Legend for Table 39:

1 - Rupture-resistance, kgf/cm<sup>2</sup>; 2 - Relative elongation, %;  
3 - Residual elongation, %; 4 - Shore hardness; 5 - Resistance to tearing, kgf/cm; 6 - Abrasion-resistance, cm<sup>3</sup>/kwh; 7 - Brittleness temperature, °C.

---

Ingredients Ингредиенты	Recipe Рецептура		
	№ 1	№ 2	№ 3
1 Полимер (ХСПЭ) . . . . .	100	100	100
2 Каннфоль гидрированная . . . . .	2,5	2,5	10,0
3 Сажа ламповая или канальная . . . . .	—	20	40
4 Мел осажденный . . . . .	80	—	—
5 Окись магния . . . . .	20	20	—
6 Окись свинца . . . . .	—	—	40
7 Тиурам . . . . .	1,0	0,2	—
8 Альтакс . . . . .	—	2,2	—
9 Каптакс . . . . .	—	—	3,0
10 Неозон Д . . . . .	—	1,0	—

Table 38. Composition (in parts by weight) of rubbers based on KhSPE.

Properties Показатели	Recipe Рецептура		
	№ 1	№ 2	№ 3
1 Сопротивление разрыву, кгс/см <sup>2</sup> . . . . .	243	115	237
2 Относительное удлинение, % . . . . .	200	220	225
3 Остаточное удлинение, % . . . . .	5	10	12
4 Твердость по Шору . . . . .	77	65	85
5 Сопротивление раздиру, кгс/см . . . . .	64	54	40
6 Сопротивление истиранию, см <sup>3</sup> /кст·ч . . . . .	—	190	—
7 Температура хрупкости, °С . . . . .	—40	—36	—40

Table 39. Physico-mechanical properties of rubbers based on KhSPE.

Colored lacquer compositions based on KhSPE in the form of organodispersions harden at room temperature<sup>44</sup>. The coatings obtained in this way have good mechanical properties and are resistant to ageing and the action of oxidizers. The high adhesion to metals improves in the process of utilization and the range of operating temperatures is approximately from -50 to +120°C.

Fluorine-containing elastomers, which differ from other rubbers in their increased chemical stability and high thermal stability, are more satisfactory. They include: copolymers of vinylidene fluoride with trifluorochloro-

ethylene (elastomer Kel-F of brands 3700 and 5500) and with hexafluoropropylene (vitones A, A-NV, fluorel), fluoroacrylate polymers (elastomers 1F4 and 2F4), fluorinated silicone rubbers (silastic LS-53), etc<sup>45-47</sup>.

Vitones are fluorinated rubbers which are obtained by the water-emulsion polymerization of vinylidene fluoride and hexafluoropropylene at 100°C in an oxidizing-reducing medium. The copolymer has a linear structure, consisting of alternating methylene and difluoromethylene groups, among which are very short perfluorocarbon side-chains. It is very stable.

Vitone is a soft, white, translucent, rubber-like material of density 1.8 g/cm<sup>3</sup>. The molecular weight of vitone A is 100,000 and that of vitone A-NV is 200,000. Recently vitone V has been introduced, with a viscosity intermediate between vitones A and A-NV.

Rubber mixtures of vitone V are superior to vitones of other brands in elasticity, thermal stability, brittleness temperature, and resistance to nitric acid and several other media.

The increased chemical and thermal stability of vitones can be explained by the high fluorine-content (up to 65%). Vitones are manufactured by the Dupont Company<sup>97,98</sup>.

The vulcanization of vitons occurs by reaction with polyfunctional amines and peroxides or under the influence of  $\beta$ - or  $\gamma$ -radiation. Amines cause premature vulcanization (scorching), and therefore salts are normally used (for example, the carbamate of hexamethylenediamine). Thermal black, gas black and metal oxides (magnesium, calcium, lead or a mixture of zinc oxide and dibasic lead phosphite) are used as fillers to facilitate the process of peroxide vulcanization.

Vitones are always vulcanized in two stages: first, under pressure at 150 °C for 30 min, and then completion of the vulcanization by heating in a thermostat or oven for 24 hrs at 200-150 °C.

Fluorinated rubber (analogous to vitones) is produced by the Kellogg Co. under the tradename "fluorel" (formerly called elastomer 214 and Kel-F-2140). It is a copolymer of vinylidene fluoride and hexafluoropropylene (70:30). Fluorel is a saturated polymer which contains more than 60% fluorine. It is vulcanized in two stages, with the same reagents and under the same conditions as vitones.

Table 40 shows examples of a few typical recipes for resin mixtures based on vitones and fluorel, and their physical and mechanical properties are listed in Table 41.

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Legend for Table 40:

- 1 - Ingredients; 2 - Vitone A; 3 - Vitone A-NV; 4 - Vitone V;  
5 - Fluorel; 6 - Polymer; 7 - Carbon black; 8 - Magnesium oxide;  
9 - Hexamethylenediamine carbamate.
- 

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Legend for Table 41:

- 1 - Properties; 2 - Vitone A; 3 - Vitone A-NV; 4 - Vitone V;  
5 - Fluorel; 6 - Density, g/cm<sup>3</sup>; 7 - Brittleness temperature, C;  
8 - Strength under tension, kgf/cm<sup>2</sup>; 9 - Relative elongation at rupture, %; 10 - Shore A hardness.
- 

A valuable property of fluorine-containing elastomers is their ability to withstand protracted use at high temperatures: for vitones, 200-220 °C;



Ингредиенты	Витон А	Витон А-НВ	Витон В	Флюорел
6 Полимер . . . . .	100	100	100	100
7 Сажа . . . . .	25	25	20	15
8 Окись магния . . . . .	20	15	15	20
9 Карбонат гексаметилен- диамина . . . . .	1,5	1,5	2	1,4

Table 40. Composition (in parts by weight) of resins based on fluorinated rubbers.

Показатели	Витон А	Витон А-НВ	Витон В	Флюорел
6 Плотность, г/см <sup>3</sup> . . . . .	1,8	1,8	1,86	1,85
7 Температура хрупкости, °С . . . . .	-45	-47	-49	-45
8 Прочность при растяжении, кгс/см <sup>2</sup> . . . . .	155-190	190-218	158	165
9 Относительное удлинение при разрыве, % . . . . .	180-460	190-250	390	225-320
10 Твердость по Шору А . . . . .	71	71-75	74	65-71

Table 41. Physical and mechanical properties of resins based on fluorinated rubbers.

for fluorel, 230-260°C, and up to 315 and even 360°C for short times. They retain their elasticity at low temperatures (from -40 to -50°C).

Vitone resins can be used for the insulation of conductors at low voltages. The specific volume electrical resistance of vulcanized rubbers based on these materials is  $2.5 \times 10^{12}$  ohm-cm for Vitone A,  $1.4 \times 10^{14}$  ohm-cm for Vitone V and  $1.3-2.0 \times 10^{13}$  ohm-cm for fluorel.

Vulcanized fluorinated rubbers are distinguished by extraordinary chemical stability: they are resistant to atmospheric effects, ozone, oxidizing agents (including 90% hydrogen peroxide and fuming nitric acid), aliphatic-, aromatic- and chlorinated hydrocarbons, aromatic amines, petroleum and other fuels and oils. They are also stable at high temperatures in dilute and

concentrated inorganic acids and bases. They are soluble in ketones, aldehydes, ethers and organic acids.

Solutions of vitone in ketones are used for making films and for thermally- and chemically-stable coatings on fabrics. Solutions of fluorel (25%) in methylethylketone, toluene or isopropyl alcohol are also used to obtain strong, chemically-stable coatings.

Since they are chemically stable, vulcanized fluorinated rubbers retain their strength and elasticity well when exposed to aggressive media.

Vitone mixtures can be processed readily with the ordinary equipment of the rubber industry. They are extruded at 63-70°C and calendered with a roller temperature of 50°C. In spite of the fact that its viscosity is higher than that of other rubbers, fluorel can be rolled and formed easily on standard equipment. The casting temperature of fluorel is 145-160°C, but it is used to make tubing by the extrusion method at 66-76°C.

Rubbers based on vitones and fluorel can be cemented or vulcanized to metals by means of silicone adhesives, but the adhesion obtained in this way is only 3.5 kgf/cm<sup>2</sup>. For items operating at temperatures up to 225°C, it is recommended that vitone rubbers be fastened with a cement based on the vitone itself. The vulcanizing mixtures are solutions of vitone in methylethylketone with hexamethylenediamine carbamate or triethylenetetramine<sup>99</sup>.

Vitones are used to make sealing rings, gaskets, packing, pressure hose, fuel tanks, protective coatings, cements and insulation for conductors<sup>100</sup>. Vitone tubing is very smooth and withstands the simultaneous influence of high temperatures (up to 200°C) and aggressive media. It is recommended for transporting petroleum products, aromatic compounds, halogen-containing

hydrocarbons, oxidizing media, special fuels, lubricating oils and hydraulic fluids. Vitone is used to make regenerator tubing for use in a toxic atmosphere, and it also can serve as an elastic covering for cables. Fluorel is used in aircraft- and rocket construction for sealing fuel compartments, for fuel- and hydraulic hoses and for insulation. In the chemical industry, it is used for gaskets which are in contact with aggressive liquids, and in automobile manufacture it is used for sealing gear boxes, making brakes, etc.

Fluorinated rubbers of these types (products of the emulsion-polymerization of fluoro-olefins) are manufactured by domestic industries under the brands SKF-32 and SKF-26 (VTU 46-10--59 and VTU 825-60). Resins based on these rubbers are familiar under the brands IRP-26 (VTU LSNKh 30016-59), 1136 and 2093. These rubbers are produced in the form of white or black sheets of thickness 1.4-2.0 mm. They are used at temperatures from -60 to +200°C as sealing and electrically-insulating gaskets in electrolytic condensers filled with 38% sulfuric acid.

The physical and mechanical properties of the rubber IRP-1064 are listed below:

Limit of strength under tension, $\text{kgf/cm}^2$ . . . . .	not less than 150
Relative elongation at rupture . . . . .	not less than 150
Residual elongation at rupture, % . . . . .	not more than 15
Specific volume electrical resistance, ohm-cm	
at 20°C . . . . .	not less than $1 \times 10^{13}$
at 200°C . . . . .	not less than $5 \times 10^8$
Electric strength, kv/mm . . . . .	not less than 15

The fluorinated rubbers 1F4 and 2F4, based on fluoroacrylate polymers, are vulcanized by amines at 154°C for 30 min in the presence of sulfur. The

resin is made by mixing 100 parts of fluorinated rubber by weight with 35 parts of lampblack, 1.25 parts of triethylenetetramine and 1.0 parts of sulfur (standard recipe). The vulcanized rubbers formed have the properties shown in Table 42.

Legend for Table 42:

A - Properties; B - Fluorinated rubbers;

1 - Limit of strength under tension,  $\text{kgf/cm}^2$ ; 2 - Relative elongation at rupture, %; 3 - Shore hardness; 4 - Swelling in benzene, %;

5 - Temperature limit of use,  $^{\circ}\text{C}$ .

A Показатели	B Фторкаучуки	
	1F4	2F4
1 / Предел прочности при растяжении, $\text{кгс/см}^2$ . . . . .	84	70
2 Относительное удлинение при разрыве, % . . . . .	360	400
3 Твердость по Шору . . . . .	52	52
4 Набухание в бензоле, % . . . . .	26	19
5 Температурные пределы применения, $^{\circ}\text{C}$ . . . . .	от -50 до +200	от -50 до +200

Table 42. Physical and mechanical properties of vulcanized rubbers based on fluoroacrylate rubbers.

Fluoroacrylate rubbers are appreciably more stable than nitrile rubbers, but they are somewhat less stable than vitone and fluorel.

Fluorosilicone rubbers. The chemical stability of silicone rubbers, which are characterized by high thermal stability, may be increased by fluorinating them. The fluorosilicone rubbers obtained (for example, silastic LS-52, a rubber based on trifluoropropylmethyldichlorosilane) have satisfactory strength properties, elasticity at low temperatures and increased chemical

stability<sup>101</sup> (Table 43).

Legend for Table 43:

A - Aggressive medium; B - Temperature, °C; C - Change of volume, %;

D - Change of hardness;

1 - Acetone; 2 - Aniline; 3 - Oil; 4 - Same; 5 - Carbon tetrachloride; 6 - Ethanol; 7 - Xylene; 8 - Nitric acid; 9 - 10%; 10 - concentrated; 11 - Sulfuric acid; 12 - Sodium hydroxide; 13 - 50%;  
14 - Decomposes.

A Агрессивная среда	B Температура °C	C Изменение объема %	D Изменение твердости
1 Ацетон . . . . .	24	+81	-21
2 Анилин . . . . .	24	+4	-1
3 Масло . . . . .	150	+4	-6
4 То же . . . . .	200	+5	-14
5 Четыреххлористый углерод . . . . .	24	+21	-6
6 Этиловый спирт . . . . .	24	+5	-2
7 Ксилол . . . . .	70	+21	-8
8 Азотная кислота			
9 10%-ная . . . . .	24	+1	+2
10 концентрированная . . . . .	24	+4	+1
11 Серная кислота			
7 10%-ная . . . . .	24	0	0
12 концентрированная . . . . .	24	14 Разрушается	
12 Гидроксид натрия			
9 10%-ная . . . . .	24	-2	-4
13 50%-ная . . . . .	24	+1	-4

Table 43. Chemical stability<sup>102</sup> of silastic LS-53.

Like other fluorinated rubbers, fluorosilicone rubbers are vulcanized in two stages: at 150 °C under pressure for 1 hr and at 200 °C in an oven or thermostat for 24 hrs. The vulcanizing agents are peroxides.

Silastics have good oil-gasoline stability and are 7-10 times more resistant to solvents (isooctane, xylene, carbon tetrachloride) than dimethylsiloxane resins.

The physical and mechanical properties of silastic LS-53 are listed below:

Density, g/cm <sup>3</sup> . . . . .	1.4
Limit of strength under tension, kgf/cm <sup>2</sup> . . .	70
Relative elongation, % . . . . .	55-60
Shore hardness . . . . .	170-200
Brittleness temperature, °C . . . . .	68
Useful temperature range, °C . . . . .	-70 to +260

Data on the chemical stability of KhSPE and fluorinated rubbers in various media are given in Chapter III.

Polyurethane rubbers. Polyurethanes are very promising polymers which also can be used to obtain rubber. They are products of the polycondensation of diisocyanates with high-molecular-weight glycols<sup>47-50</sup>.

Polyurethane polymers are used to make elastic, water- and wear-resistant, colored-lacquer protective coatings for metals, leather, wood and other materials<sup>103,104</sup>.

Domestic industries produce the following lacquers based on polyurethane polymers: UR-71, UR-930 (VTU P-120--60); primer UR-01; electrically-insulating lacquers UL-1 and UL-2 and sealing compounds K-30, K-31, KG-102, KT-102, etc. For tropical climatic conditions, the following epoxide-urethane coatings are recommended: lacquer UR-231 (VTU GIPI 4-337--61), lacquer UR-31 and primer UR-012. These lacquers are distinguished by high water-resistance and good protective properties. They are superior to epoxide coatings in this respect. Depending on their composition and properties, polyurethane lacquers may harden at ordinary temperatures or at elevated temperatures.

Polyurethane rubbers are produced abroad under the tradenames vulcollan,

adiprene, vibratane, vulcaprene, estane, etc. They also display a wide variety of physical, chemical and mechanical properties. Some of them, such as adiprene L, for example, are obtained in the form of liquid polymers which are used to make the desired products by casting or molding.

Other types of polyurethane rubbers can be made into elastic resins with ordinary equipment and can be vulcanized with sulfur and peroxides.

In the USA they produce four types of urethane rubbers, classified according to their properties and methods of forming:

- 1) liquids, suitable for casting in molds with subsequent thermochemical vulcanization (adiprene L, neotane, multratane);
- 2) regular urethane rubbers, processed on equipment used for ordinary resins (gentane, vibratane, certain brands of adiprene);
- 3) estane thermoplastic rubber, suitable for extrusion or molding (brands 5740X1, 5740X2 and 5740X7);
- 4) texin scorched thermoplastic rubber (brands 192A, 280A, 355A and others), suitable for pressure-casting and extrusion at temperatures which guarantee complete vulcanization (150-170°C and higher).

Polyurethane rubbers adhere well to metals, can be used in the liquid state, and can be vulcanized in air by the open method (with or without heating). These valuable properties make them useful as coatings: sealing, wear-resistant, abrasion-resistant, and for protection against fuels, oils, solvents and various chemical media. Especially attractive to investigators is the possibility of obtaining coatings with high resistance to erosion and abrasion, since the wear-coefficient of urethane coatings is appreciably lower (60%) than chlorinated rubber (220%) or epoxide (190%) coatings. Information is available on the use of vulcollans for wear-resistant coatings, on

the protection of interior surfaces of gas tanks and other containers in chemical plants with polyurethane resins, and also on the production of pipe coated with these resins. This pipe, which comes in diameters from 76 to 254 mm and lengths up to 914 mm, is used for transporting abrasive materials: sand, suspensions, dry chemicals, etc. Polyurethane resin coatings of piping systems are 6.4 mm thick; they are resistant to aggressive gases. According to the available data, polyurethane elastomers are stable at 20 and 60°C in water and in solutions of ammonium nitrate, ammonium sulfate, sodium chloride and sodium hypochlorite. They swell slightly and corrode in solutions of potassium bichromate and in hydrogen sulfide. The coating are attacked by dry and moist chlorine, as well as by the following acids: nitric, hydrobromic, sulfuric, hydrochloric, phosphoric, chromic, hydrofluoric, chlorosulfonic, lactic and acetic.

Data on the stability of polyurethane resins in 100% butyric acid are given below:

Swelling at 22 °C, % . . . . .	1.3
Change of relative elongation, % . . . . .	10
Loss of strength, % . . . . .	23

Polyurethane elastomers are completely stable in the following organic media: gasoline, glycerine, vegetable oils, aliphatic hydrocarbons (propane); they are sufficiently stable in glycols, butanol, ethanol, 37% formaldehyde, tetraethyl lead; they dissolve in acetone, benzene, amyl acetate, carbon bisulfide, carbon tetrachloride, methanol; they swell appreciably in toluene (43%) and in trichloroethylene (170%).



## Colored-lacquer Materials<sup>51,52</sup>

The selection of colored-lacquer materials, which includes primers, fillers, lacquers, paints and enamels, is extremely large. The nonmetallic polymeric materials of this group are designed to protect from atmospheric effects (surrounding media), chemical media, water, gasoline, oil, high temperatures, and also to serve as electrical insulation.

Colored-lacquer coatings\* are divided into two groups, according to the

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\* In the choice of colored-lacquer coatings, it is very convenient to use the machine-construction standard MN 4200-62.

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climate in which they are to be used: temperate-continental and tropical.

Until recently, the chemically stable colored-lacquer materials used to protect metallic items from the direct action of chemically aggressive media consisted mainly of perchlorovinyl resins and, to a lesser degree, phenolic resins and bitumens. During the past ten years, epoxide resins have begun to be used for protection from corrosion. These materials have high chemical stability in acidic and basic media and in solvents: alcohols, aliphatic and petroleum hydrocarbons, aldehydes, benzene, etc. In addition, epoxide materials can be hardened without heating and they withstand appreciable (up to 120°C) operating temperatures.

In choosing a coating for the protection of equipment, it is necessary to take into account the operating conditions (constant or periodic exposure to chemically aggressive media). The intermittent action of a medium on a colored-lacquer coating is less serious than constant exposure to the medium.

Depending on the coating selected, it may include a primer, filler,

enamel and lacquer. Thus, perchlorovinyl coatings, as a rule, consist of a primer, enamel and lacquer; epoxide coatings consist only of a primer or of a primer and enamel; phenolic (bakelite lacquer) coatings consist only of a lacquer with filler; and divinylacetylene (ethinol lacquer) coatings consist of a primer and lacquer with filler. The colored-lacquer materials which are used to obtain chemically stable coatings<sup>54,55</sup> are listed in Table 44.

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Legend for Table 44:

- A - Drying conditions; B - temperature, °C; C - time, hr;
- D - Strength and elasticity characteristics;
- 1 - Materials based on epoxide resins;
- 2 - Primer-filler; 3 - Red-brown; 4 - Enamels; 5 - Green; 6 - Hardness by pendulum, not less than 0.5; 7 - Cream; 8 - Lacquer;
- 9 - Colorless; 10 - Films with high mechanical strength and good adhesion; 11 - Light brown;
- 12 - Materials based on perchlorovinyl resins;
- 13 - Primer; 14 - Elasticity by scale of flexibility 1 mm; 15 - Various; 16 - Strength of film in flexure by scale no more than 1 mm;
- 17 - Film mechanically strong; 18 - Green and white; 19 - Gray;
- 20 - Materials based on phenolic resins;
- 21 - Bakelite resin; 22 - According to conditions;
- 23 - Materials based on divinylacetylene polymers;
- 24 - Ethinol lacquer;
- 25 - Bituminous materials;
- 26 - Acid-resistant lacquer 411; 27 - Black; 28 - Elasticity by scale of flexibility 3 mm; 29 - Bituminous lacquer 67; 30 - Coal-tar lacquer;
- 31 - Strength of film in flexure by scale no more than 5 mm;
- 32 - Materials based on rubbers;

Material Материал	GOST or TU ГОСТ или ТУ	Color Цвет	A Режим сушки		D Показатель прочности и эластичности
			т температура, °C	с время, ч	

1 Материалы на основе эпоксидных смол

2 Грунт-шпатлевка Э-4020 Е Э-4021	ВТУ КУ 498-57 ВТУ КУ 498-57	Красно-коричневый	18-23 или 50-60	24 8	— —
4 Эмали ОЭП-4171 ОЭП ОЭП-4173	ТУ ЯН 21-57 ТУ ЯН 22-57	Зеленый 5 Кремовый 7	120 120	2 2	Твердость по маятнику, не менее 0,5 То же Same
8 Лак Э-4001  Э-4100	ВТУ УХПОЗ ТУ ЯН 35-58	Бесцветный 7 Светло-коричневый	120 150	2 1+3	Пленки высокой механичес- кой прочности с хорошей адгезией

12 Материалы на основе перхлорвиниловых смол

13 Грунт КХСГ КХСГ ХСЭ	ГОСТ 7313-55 и ТУ МХП 2280-50	Красно-коричневый Различный 15	18-23 или 60	2 1/4 1 1/4	Эластичность по шкале гиб- кости 1 мм Прочность пленки при изгибе по шкале не более 1 мм
4 Эмали КХСЛ Лак КХСЛ ПХВ-52 ОННЛХ-3 ХС-75 ХС-76 КХ-5	ГОСТ 7313-55 ТУ МХП 3559-52 ТУ МХП 1250-48 ВТУ КУ 434-55 ГОСТ 9355-60 ГОСТ 9355-60	Бесцветный 7 То же Same Зеленый и белый Бесцветный 7 Серый 19	18-23 или 60 или 60 или 60 или 60 или 60	1 0,5 3 4 2 2 1	То же Same Пленка механически прочная Прочность пленки при изгибе по шкале не более 1 мм То же Same
4 Эмаль ХС-710	ГОСТ 9355-60	Серый 19	18-23 или 60	2 1	То же Same

20 Материалы на основе фенольных смол

21 Лак бакелитовый	ГОСТ 901-56	Бесцветный 7	По режиму 22		
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25 Материалы на основе дивинилбензидиленовых полимеров

22 Лак этиловый	ТУ МХП 1267-57	Бесцветный 7	18-23	12	—
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25 Битумные материалы

26 Кислотостойкий лак 411	ГОСТ 1347-41	Черный 27	18-23	48	Эластичность по шкале гиб- кости 3 мм
27 Лак битумный 67	ГОСТ 312-43	Черный 27	18-23	2	Эластичность по шкале гиб- кости 3 мм
30 Лак каменноугольный	ГОСТ 109-60	Черный 27	18-23	24	Прочность пленки при изгибе по шкале не более 5 мм

32 Материалы на основе каучука

33 Эмаль 55 на основе каучука СРН	—	—	180	1	—
34 Хлоркаучуковый лак	—	—	18-23	24	—

Table 44. Characteristics of colored-lacquer materials used to obtain chemically stable coatings.

Legend for Table 44 (con't):

33 - Enamel 55, based on SKN rubber; 34 - Chlorinated-rubber lacquer.

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### Polymeric Cementing Materials

Cementing compounds based on phenol-formaldehyde resins, under the name arзамite cements, are used widely for fettling work. They are used as an independent fettling material or as a sublayer for sealing joints of inlaid linings and for cementing faolite, antegmite and other plastics. Arзамite cements are made up of two components: arзамite-solution (that is, phenol-formaldehyde resin) and arзамite-powder, which consists of a filler (quartz flour, silica, barium sulfate, graphite) and a catalyst-setting-accelerator (paratoluylsulfochloride). The components are mixed within an hour before using, since these cements set quickly (in a day at room temperature and in a few hours at 70°C). At present there are seven well-known grades of arзамite, differing in their resistance to acids and bases, thermal conductivity and thermal stability (Table 45). Arзамite-6 is used at temperatures up to 160-180°C and the other arзамites can be used at temperatures up to 120°C.

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Legend for Table 45:

A - Grade of arзамite cement; B - Limit of strength under tension,  $\text{kgf/cm}^2$ ; C - Adhesion; D - to St. 3, protective sublayer; E - to impregnated graphite;

1 - Arзамite; 2 - As acid-resistant cement; 3 - As acid-base-resistant cement; 4 - For cement which is resistant to hydrofluoric acid;

5 - As acid-resistant and heat-conducting cement; 6 - As acid-base-resistant and heat-conducting cement; 7 - As acid-resistant, heat-conducting and thermally-stable (up to 160-180°C) cement,

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А Марки замазок арзамит	ТУ	Предел проч- ности при растя- жении кгс/см <sup>2</sup>	С. Адгезия		Use Применение
			к Ст. 3, защит- ной по- дслою	к про- пан- ному граф- ту	
Арзамит-1	МХП 522-54	51-54	40	39-40	В качестве кислото- стойкой замазки
Арзамит-2	МХП 522-54	38-40	41	38-40	В качестве кислото- стойкой замазки
Арзамит-3	МХП 522-54	39-45	40-45	40-45	В качестве кислото- стойкой замазки для фтористоводородной кислоты
Арзамит-4	МХП 543-58	49-50	40-50	35-50	В качестве кислото- стойкой и теплопро- водной замазки
Арзамит-5	ВТУ МХП 4539-59	45-65	38-43	44-51	В качестве кислотоце- лочестойкой и тепло- проводной замазки
Арзамит-6	—	—	—	—	В качестве кислото- стойкой теплопровод- ной и термостойкой (до 160-180 °C) за- мазки
Арзамит-7	—	45-50	25-35	25-40	В качестве кислотоце- лочестойкой замазки

Table 45. Characteristics and uses of arзамite cements.

#### Wood, Carbon, Graphite

Wood, carbon and graphite are non-plastic corrosion-resistant materials.

Wood is a material with low corrosion-resistance. It decomposes under the influence of oxidizers and concentrated acids. In spite of this, however, it is frequently used for making apparatus of simple shapes, ducts, parts of filtering equipment and crates for chemical products.

The stability of wood in aggressive media depends on its nature. If it is impregnated with phenol-formaldehyde resins, for example, its stability is increased. After impregnation and heating to 125-130 °C (to set the resin), wood becomes sufficiently stable in many aggressive media, with the exception of oxidizers, bases and some organic solvents. Plywood pipe<sup>26</sup> (GOST 7017-64),

with inside diameter from 50 to 300 mm and wall thickness from 6.5 to 13 mm (brands F1 and F2), is used in the chemical industry for transporting weakly aggressive media. Brand F1 plywood tubing is designed for an operating pressure differential of 10 atm, and brand F2 is designed for a pressure of 5 atm with tubing diameter 100 mm.

Carbon has very high corrosion-resistance, but it has not been widely used in equipment-construction, mainly because of its low strength. Since it is a porous material, it is used to make filters, gas-mixing diffusers and other items of a similar nature. Carbon tiles and fettling blocks of anthracite and pitch (TsMTU-48) are used for lining large-scale equipment, for example, digesters for the cellulose-paper industry. Table 46 shows the physical and mechanical properties of carbon.

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Legend for Table 46:

- A - Basic characteristics; B - Graphite; C - untreated; D - treated;  
E - Antegmite ATM-1; F - Graphitelite (for casting); G - Carbon;  
1 - Density,  $\text{g/cm}^3$ ; 2 - Limit of strength,  $\text{kgf/cm}^2$ ; 3 - under compression; 4 - under tension; 5 - in flexure; 6 - Thermal conductivity,  $\text{kcal/m-hr-deg}$ ; 7 - Coefficient of linear thermal expansion;  
8 - Temperature limit of use.
- 

Graphite has good thermal conductivity and high chemical stability. It is used as a structural material in the production of chemical apparatus<sup>5,56-58</sup> and heat-exchange equipment. Since natural graphite contains impurities, the chemical industry uses synthetic electrode graphite, with porosity of 20-30% and sometimes as high as 50%.

In order to eliminate the porosity of graphite, it is impregnated with

А Основные показатели	Б Графит		Е Антегмит АТМ-1	F Графито- лит (для литья)	G Уголь
	непропи- танный	пропитан- ный			
1 Плотность, г/см <sup>3</sup>	1,45	1,8	1,8	1,1—1,2	1,04
2 Предел прочнос- ти, кгс/см <sup>2</sup>					
3 при сжатии	173	850	1000—1200	900	21—53
4 при растя- жении	67—70	140	180—220	100—110	5,6—13,3
5 при изгибе	113	311	400—500	300	11—42
6 Теплопровод- ность, ккал/(м·ч·град)	75—100	75—100	30—35	0,2—2,0	1,5—2,2
7 Коэффициент температурного линейного рас- ширения, α·10 <sup>6</sup>	2,9	7,5	8,5	—	—
8 Температурный предел приме- нения, °C	—	180	170	160	—

Table 46. Physical and mechanical properties of graphitic materials and carbon.

synthetic resins (mainly phenol-formaldehyde). It then acquires high mechanical strength and impermeability. It is used to make heat-exchange equipment of various types: submerged, sheathed-tube, "tube-in-tube" and block.

In addition to heat-exchangers, graphite is used to make absorbers and, sometimes, centrifugal and rotary pumps. It is also used in the form of tiles for fettling chemical apparatus.

Plastics based on graphite have been used widely in the chemical industry. A particular example is antegmite, in which the binder is phenol-formaldehyde resin and the filler is powdered electrode graphite. Antegmite is formed by compression-molding at high temperatures and pressures. There are three familiar brands of antegmite: АТМ-1, АТМ-10 (TATEN-0) and АТМ-1G (TATEN-G). Most common is АТМ-1, which is used to make tubing (VTU N-234--54), fettling tile (VTU N-367--55) and centrifugal, horizontal, single-stage pumps with moving parts of АТМ-1.

The thermal conductivity of antegmite is three times lower than impregnated graphite, but appreciably higher than other plastics. The coefficients of linear expansion of ATM-1 and steel are similar, which is an advantage in the fettling of steel vessels with ATM-1 tile.

The graphitic plastics also include cast-graphite or graphitolite, which is characterized by high fluidity. For this reason it is used to make items by the so-called method of cold casting in closed or open molds, without pressure and at ordinary temperatures. These items include valves, centrifugal pumps and other objects with complicated shapes which cannot be made of impregnated graphite or antegmite. Graphitolite has the same chemical stability as graphite and ATM-1, but, in contrast to the latter, it has almost no thermal conductivity. There are three well-known brands of graphitolite: NL, 2FNL and 5EFNL, which have different properties and are used for casting and fettling. The properties of brand NL graphitolite and other graphitic materials are listed in Table 46.

All graphitic materials are distinguished by high chemical stability. They are attacked only by basic media and by halogens: bromine, iodine, fluorine (they are resistant to chlorine). Graphite and graphitic plastics are used not only for the construction of chemical apparatus, but also as antifriction materials.

Impregnated graphite is produced abroad under the tradenames carbaite (USA), Igurite (GDR), diabon (FRG), etc., and graphitolite under the name gussigurite (GDR).

#### Nonmetallic Materials of Inorganic Origin

These are mainly fettling and accessory materials<sup>59</sup>. Figure 16 shows a



rough classification of these materials and their physical and mechanical properties are listed in Table 47. The natural acid-resistant materials include substances consisting chiefly of silicon dioxide, which is responsible for their high chemical stability in most aggressive media. They are attacked by fluorine compounds and by caustic and carbonate bases.

Legend for Figure 16:

- 1 - Nonmetallic materials of inorganic origin; 2 - Fused materials;  
3 - Silicate materials based on cements; 4 - Stone cast from diabase and basalt; 5 - Fused quartz; 6 - Cements; 7 - Concretes; 8 - Silicate glass; 9 - Enamels; 10 - Plasters; 11 - Ceramic materials;  
12 - Natural acid-resistant materials; 13 - Acid-resistant materials; 14 - Refractory materials; 15 - Granite; 16 - Beshtaunite; 17 - Thin ceramic; 18 - Asbestos; 19 - Andesite.

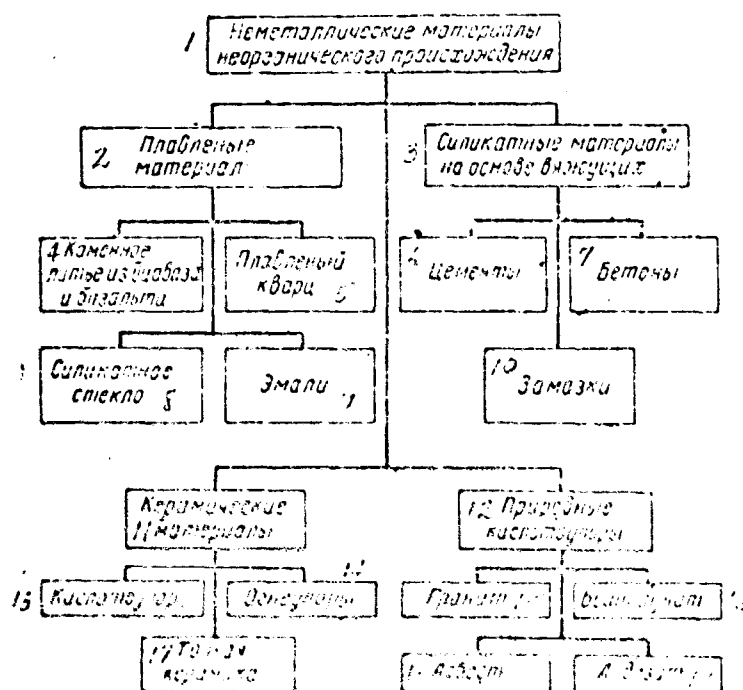


Figure 16. Classification of nonmetallic materials of inorganic origin.

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Legend for Table 47:

- A - Material; B - Density,  $\text{g/cm}^3$ ; C - Limit of strength,  $\text{kgf/cm}^2$ ;  
D - under tension; E - under compression; F - in flexure; G - Water  
absorbance, %; H - Porosity, %; I - Temperature limit of use;  
J - Thermal conductivity,  $\text{kcal/(m-hr-deg)}$ ; K - Coefficient of linear  
thermal expansion.
- 1 - Andesite; 2 - volumetric mass; 3 - Beshtaunite; 4 - Not less than;  
5 - Not more than; 6 - Granite; 7 - Diabase; 8 - Basalt; 9 - Quartz  
glass; 10 - Glass 13 for tubing; 11 - Thermostable borosilicate glass;  
12 - Acid-resistant enamels; 13 - Acid-resistant ceramic tile (GOST  
961--57); 14 - Porcelain; 15 - Andesitic plaster; 16 - Diabase plas-  
ter; 17 - softening temperature; 18 - Sulfur cement; 19 - Acid-resis-  
tant concretes; 20 - Appreciable;
- 21 - Yu. V. Dereshkevich, "Acid-resistant Structures in the Chemical  
Industry"<sup>59</sup>;
- 22 - Handbook for special operations<sup>60</sup>.
- 

Granites are used in the construction of absorption towers with media  
temperatures up to 200-250°C. Beshtaunite and andesite, which are highly  
acid-resistant, are used exclusively as fettling materials. They are resis-  
tant to inorganic acids and aggressive gases at 800-900°C. In addition,  
beshtaunite, like granite, is used in the construction of acid towers and  
andesite is used widely as a filler in cementing compounds.

The acid-resistant material asbestos is used as a filler and in gaskets,  
packing and filter cloth. Asbestos is classified as anthophyllitic (acid-  
resistant) or chrysotilic (more stable in basic media).

А Материал	В Плотность, г/см <sup>3</sup>	С Предел прочности, кг/см <sup>2</sup>			Г Водопоглощение, %	Н Пористость, %	Т Температурный предел при испытании, °С	J Теплопроводность, ккал/(м·град)·с·10 <sup>3</sup>	K Коэффициент линейного температурного расширения α·10 <sup>6</sup>
		Д при растяжении	Е при сжатии	F при изгибе					
1 Алмаз (ТУ МСПИ 93—52)	2,2—2,7 (объемная масса)	—	500—900* 600—2 400**	140—150	2,0—10,5	2,5—14	600	0,9	6,0
2 Бесталит (ТУ МХП 1585—47)	2,4—2,65 (объемная масса)	—	600—1 500	Не мен. 165	Не более 3,5	1,0—1,2	600	—	6,4
3 Гранит	2,35—2,65 (объемная масса)	—	450—2 400* 600—3 000**	230	0,3	1,0	200—250	—	8,0
7 Диалит	2,95—3	200—250	2 000—4 000	200—400	0,1—0,2	—	150	0,85—1,2 1,8—1,9**	7—10
8 Базальт	2,9—3	200—250	2 000—4 000	—	0,1—0,2	—	>200	1,8—1,9	6—8
9 Хлоридное стекло	2,15	450	3 500	400	—	3—4	~1200	0,9—1,0* 2,5—3,5**	0,4—0,55
10 Стекло 13 для труб	2,6	450—700	—	700—1 100	—	—	90—100	0,8	5—7
11 Термостойкие боросиликатные стекла	2,2—2,4	600—900	6 000—13 000	—	—	—	300—400	0,2	3,6
12 Кислотоупорные эмали	2,1—2,5	300—500	6 000	—	—	—	300	0,8—1,05	10—11,5
13 Кислотоупорные керамические плитки (ГОСТ 901—57)	2,4—2,56	50—100	≥300	>150	6—9	—	≥120	0,9—1,05	4,3—4,9
14 Фурор	2,3—2,5	320—450	4 500—5 000	—	0,5	<0,1	1 000	0,7—0,9	2,5
15 Андизитовая замазка	2,64	25—35	180—250	—	—	—	—	—	18,8
16 Диалитовая замазка	1,95—2,0 (объемная масса)	30—70	400—500	—	—	5—14	17 800 (температура размягчения)	0,5	—
17 Цемент серный	2,1—2,2	50—55	600	100—110	0	0,52	95—100	—	15
18 Кислотоупорные бстоны	2,2—2,3 (объемная масса)	12—16	110—120* 120—350**	—	—	Значительная	200—900	0,7—1,0	8

\* Ю. В. Дереминич, «Кислотоупорные сооружения в химической промышленности».  
 \*\* Справочник по специальным работам.

Table 47. Physical and mechanical properties of nonmetallic corrosion-resistant materials of inorganic origin.

Fused silicate materials include diabase and basalt cast stone, used in the form of tiles for fettling (VTU MKhP 9029--55) and, more rarely, for making components of chutes, piping systems, sleeves, and spheres for ball mills. These strong, hard materials with high chemical stability are brittle and cannot withstand rapid temperature oscillations. Quartz glass (fused quartz) is molded into containers, tubing, of columns and absorbers and sometimes it is pressed into fettling tiles. Silicate glass is used to make fettling tiles and as a structural material for tubing (GOST 8894-58), elbows, tees, condensers, fractionating columns and other equipment.

Borosilicate glass has increased thermal stability, so that tubing made of this material can be used in the temperature range from -50 to +400°C. However, it must be remembered that glass of any composition is attacked by hydrofluoric acid and concentrated solutions of bases (with the exception of special base-resistant glasses).

Acid-resistant enamels. Vitreous thin-layer coatings are subdivided into two groups: primers and coverings. The thermal stability of these enamels can be as high as 300-400°C. Domestic industries produce a variety of enameled items which are widely used in chemical processes. These items have high corrosion-resistance in all organic and inorganic media, with the exception of fluorine compounds and hot concentrated alkali solutions. The principal kinds of enameled chemical equipment are: storage tanks, with and without linings, various types of reactors, autoclaves, vacuum apparatus, evaporating pans, heat-exchangers (coil, "tube-in-tube" or "vessel-in-vessel"), condensers, sheets and caps of fractionating columns, various filters, crystallizers, mixers, pipe and fittings, valves and other equipment<sup>61</sup>.

Ceramic acid-resistant and refractory items are made by molding natural silicate materials (basically clay with certain additives<sup>62</sup>) and then annealing until sintering is complete. Ceramic materials are subdivided into two groups, depending on the degree of water absorption: stone-ceramic and porcelain with water absorbance less than 5%, and refractory and filtering materials with water absorbance greater than 5%. Ceramic materials of the first group are used for fettling tiles of various kinds (acid- and heat-acid-resistant, ceramic, heat-acid-resistant for hydrolytic processes) and as structural materials for the fabrication of chemical equipment. Materials of the second group are used for filters and furnace linings. Ceramic heat-exchangers, pumps, reservoirs, reactors with stirrers, ball mills, blowers, piping systems, valves, fittings, ceramic caps for absorption towers and other equipment<sup>26,105</sup> are used in chemical processes when strongly aggressive media are involved.

Porcelain is a thin ceramic material which is hard or soft, depending on the annealing temperature. Soft porcelain has less strength and thermal stability than hard porcelain.

Hard porcelain is used to make fettling tiles which are distinguished by impermeability and high mechanical strength. It is also used for various items of small volume (up to 500 l) and dimensions: vacuum apparatus, containers, pickling baths, coils, valves, tubing<sup>26</sup>, filters, pump components, etc.

Silicate cements are chemically stable materials which include plasters, cements and concretes. They are compounds which consist of a finely ground mineral filler and the cement itself (liquid glass or bitumen). The fillers used are gravel, sand, andesite, beshkaunite, quartzite (powdered quartz), diabase and basalt.

When the filler is mixed with liquid glass (aqueous solution of sodium silicate), sodium fluosilicate is used to accelerate setting.

The silicate acid-resistant plasters are divided into the following categories, depending on the form of the filler: diabasic, basaltic, andesitic and litharge-glycerin. The last type contains lead monoxide or red lead in addition to andesitic flour, and the liquid glass is replaced by glycerin.

Cements are classified as ordinary portland cements, aluminum sulfate cements, acid-resistant cements or sulfur cements. Sulfur cements differ from other types in composition and properties. The binder is replaced by molten sulfur and a plasticizer (thiokol or thermoprene) and the filler, as usual, is a finely-ground, acid-resistant mineral. Sulfur cement is resistant to mineral acids and solutions of their salts.

Concretes. Acid-resistant reinforced concrete is used for fettling apparatus, for laying foundations under pumps which transfer acids, for covering floors and subfloors, and for constructing large-scale apparatus, such as towers, tanks and vats.

Fireproof reinforced concrete is used at high temperatures. The reinforcement is rolled plate-, bar- or section iron of carbon steel (St. 3).

Polymer-concretes are now becoming available. These materials are obtained by combining mineral cements (cements, gypsum, lime) and fillers with organic polymeric binders (resins, rubbers, polyvinyl chloride, etc.). One example is faizol-concrete, which is based on furfural-acetone resins of various compositions, depending on the intended use. A reagent such as benzenesulfonic acid is used for setting faizol. Polymer-concretes may be used

as coatings or for reinforced structures.

### Nonmetallic Protective Coatings<sup>63-65</sup>

Nonmetallic corrosion-resistant materials are used not only for structural items, but also for protective coatings.

The protection of metals with nonmetallic coatings is accomplished by various methods, the selection of which is determined by the structure and shape of the equipment to be protected and the conditions under which it is to be used.

Plastic protective coatings. Metallic equipment is protected by coatings of, for example, viniplast or polyethylene (a film of the plastic being used is glued onto the apparatus or it is fattled) or by inserts.

Viniplast film is attached by means of perchlorovinyl cement (a solution of perchlorovinyl resin in dichloroethane, stabilized by melamine). The cement is applied by brush or by spraying in 2-3 layers onto a metallic surface which has been prepared, degreased with dichloroethane, and dried.

The protection of apparatus with inserts is more reliable than coating with films. Irregular and cylindrical parts are made by molding thermoplastic sheets, which are heated to the appropriate temperature and bent by means of wood or steel (for large sizes) forms. Irregular parts of inserts are made with special mandrels or compression molds and the molded parts are welded together. The completed insert is placed in the metallic, wood or concrete vessel, leaving a space between the insert and the walls of the vessel. A solution of liquid cement is poured into the space, directly or through special holes in a steel apparatus. The insert is filled with water while the solution is being poured in.

Inserts prepared by this method can be used only for small-scale apparatus.

In fettling, plastic plates (of viniplast, for example) of thickness 2-10 mm are fastened to the body of the apparatus by bolts with spherical heads. Each bolt is secured by a nut on the outside of the apparatus. On the inside, the slot of the bolt is filled in with acid-resistant cement and then the entire head is sealed in with thermoplast<sup>9</sup>.

Small-scale items, such as cast-iron valves, are coated by pressing-in thermoplast powder, heated with a special device to the required temperature. This temperature is 150°C for polyethylene and 250°C for fluoroplasts. In this method the body (seat) of the valve forms one part of a compression mold and the plug serves as the other. This method is used to line cast-iron plug valves with modified polytetrafluoroethylene (fluoroplast-40) and other fluoroplasts. Techniques have now been developed for the production of tubing lined with viniplast, polyethylene and other thermoplasts (VTU 289-62)<sup>26,66</sup>. Protective coatings can be obtained with thermoreactive plastics by depositing the green mix on the surface and then setting it by heat-treatment. The materials most widely used are faolite, textolite and asbovinyl<sup>20,24,25,67</sup>.

The preparation of faolite protective coatings for steel and cast-iron apparatus (faoliting or fettling) is done in the following way: sheets of raw faolite, cut to the dimensions of the apparatus and preheated to 60°C, are covered on one side with an alcohol solution (15%) of resol resin (or bakelite lacquer) and applied to the surface of the apparatus, which has been coated with the same solution. The sheets are pressed and carefully rolled to remove air from the faolite layer (the remaining bubbles are punctured and rolled again). Subelements are assembled with butt- or overlapping joints.



After the surface has been covered with faolite, a coating of bakelite lacquer is applied and the entire apparatus is placed in a polymerization chamber for setting. The temperature in the chamber is increased gradually from 60 to 130°C, with a pause after each increment of 10°C. The setting process normally takes 30 hr, although it may require 60-70 hr for large-scale items.

In the faoliting of shut-off fittings such as faucets, heated raw faolite is compressed in removable molds and then is set by the method outlined above. Using this procedure with wood or metal molds, raw faolite sheets can be formed into tubing, columns and other items. The molds may be split or sectional.

For the protection of chemical apparatus with asbovinyl coatings, the asbovinyl compound is applied with a spatula to the prepared surface of the apparatus as a primer (layer of thickness 2-8 mm). A second layer of thickness 3-4 mm is applied after the first has hardened, and a third layer of the same thickness is applied after the second has hardened. The surface being protected and the first layer of asbovinyl receive two coats of ethinol lacquer. Under natural conditions, each layer of asbovinyl dries in 5-6 days and the final setting process requires 20-30 days. The drying time can be shortened to 10 days by using warm air (40-50°C).

Coatings can be prepared from powdered polymeric materials by two methods: dusting by gas flame or vortex and depositing from suspensions. The materials used with the dusting method are mainly plastics and occasionally rubbers (when they can be obtained in the form of finely divided powders; for example, thiokol). For gas-flame dusting on an industrial scale the materials used are polyethylene, polypropylene and polyamides. However, it is also possible to use fluoreplast-3, polystyrene, polyvinylbutyral

(butvar), semisolid epoxide resins and other polymers. Gas-flame dusting is accomplished by means of special devices<sup>68-70</sup>, such as UPN-4L.

Sections of the metallic surface are heated with an acetylene flame to 200-210 °C (for dusting with polyethylene) and a stream of compressed air with plastic powder suspended in it is directed at the surface inside the stream of burning gas. The plastic particles are heated and melted in flight. When they strike the heated metallic surface, they adhere to it and fuse together to form a continuous, monolithic protective layer. The number of layers applied depends on the demands to be made on the coating.

The "vortex" method of dusting consists of heating the item to be coated to a temperature above the melting point of the plastic and then dipping it in a suspended or "boiling" bed of powder. This fluidized bed is formed by blowing compressed air (or an inert gas) through a porous diaphragm (head) which is covered with plastic powder. The suspended powder acquires the properties of a "boiling" liquid, more than doubles its volume, and freely envelopes an object immersed in it. When the powder falls on the heated surface it melts and spreads out, forming a uniform, homogeneous protective film<sup>20,71-74</sup>. The plastic powders used with the vortex dusting method are the same as those used with the gas-flame method.

The method of depositing plastic powders from suspensions is used primarily for preparing fluoroplast coatings. Fluoroplast-3 or fluoroplast-3M in the form of a 30% suspension in an alcohol-xylene mixture can be used for this purpose, as can a special finely-divided fluoroplast-4D in the form of an aqueous suspension. The suspension is deposited onto the prepared (by sandblasting) metallic surface by pouring, dipping or spraying<sup>20,75-77</sup>.

When fluoroplast-3 is applied by this method, each layer has a thickness

of no more than 15-20 microns. It is necessary to apply at least 15-16 layers in order to obtain a coating, and each layer must be dried at 100-120°C and then fused together at 260-270°C. The technique for the preparation of this kind of coating is very difficult. The first two layers comprise a primer and they contain chromic oxide (15%) to increase the adhesion. In the deposition of fluoroplast-3 suspensions, plasticizers (fluorocarbon oils and liquids) can be used to increase the thickness of each layer (by at least a factor of two). This simplifies the coating technique and reduces the number of layers to 5-7.

After the last layer of fluoroplast-3 has been deposited and fused, the object is quickly immersed in cold water and the coating hardens. No quenching is required when modified fluoroplast-3M is used to prepare coatings, and it is better in this case to cool the object slowly in a thermostat.

The 60% aqueous suspensions of fluoroplast-4D contain from 9 to 12% non-ionic surface-active agents, which stabilize these suspensions and make them capable of wetting a variety of surfaces. The techniques and procedures used to apply fluoroplast-4D suspensions are the same as for fluoroplast-3, except that the sintering is carried out at a higher temperature ( $370 \pm 10^\circ\text{C}$ ).

During the sintering process, the stabilizer is vaporized and the particles of fluoroplast-4D are converted into a homogeneous film. Slow cooling is recommended in the preparation of fluoroplast-4D coatings because it increases the adhesion of the coating. Rapid quenching in water is necessary when a free film is being made.

A coating made of fluoroplast-4D is appreciably less impermeable than one made of fluoroplast-3. It can be used for anti-adhesion, anti-friction and electrically-insulating purposes and for protection only against atmos-

pheric corrosion.

Rubber coatings. The protection of metallic equipment with rubber-based materials (rubbers, ebonites, sealants) is known as rubberizing. The process consists essentially of applying the materials in the form of crude, unvulcanized sheets and then vulcanizing them. They are fastened to the metallic surface by means of appropriate cements. The rubberizing of apparatus with sheets of PSG reinforced polyisobutylene requires no vulcanization. The PSG is fastened to the metal with cements No. 88 and No. 8 without heating, under ordinary conditions<sup>67,78,79</sup>. PSG polyisobutylene can be applied to concrete, brick and wood surfaces, as well as to metals. Moreover, it can be welded readily with an electric soldering iron or by hot air with the torches used for welding viniplast. It can also be bonded by simply wetting the surface with gasoline and then applying pressure with rollers.

PSG polyisobutylene, reinforced with carbon black and graphite, is used as an independent coating material or as a sublayer when fettling with acid-resistant tiles or bricks. It is produced in the form of sheets with dimensions 3000 x 800 x 2.5 mm. Apparatus which is to be coated with polyisobutylene must have rounded (radius no less than 5 mm) and polished corners, carefully-polished welded seams and calked, countersunk rivet heads.

Two layers of cement are applied to a surface which has been degreased, sandblasted, washed with solvent (gasoline) and dried (the first layer is allowed to dry for 2-3 hours). One layer of cement is applied to a sheet of PSG which has been trimmed to fit. After 10-30 min it is put in place, smoothing it out from center to edge like wallpaper to remove air bubbles. It is then rolled to produce a bond.

Rubber and ebonite sheets are also used for rubberizing apparatus<sup>80,81</sup>.

Depending on the construction of the apparatus, the conditions under which it operates and the aggressiveness of the medium, rubberizing may be done with the following materials: ebonite or semiebonite only, soft rubber with an ebonite sublayer, soft rubber only and vulcanized soft rubber. As a rule, the materials are folded over and applied to the metal in doubled form or in layers.

Rubbers and ebonites are fastened to metallic surfaces and to themselves by using the cement which has been recommended for each brand (see Table 36). The vulcanization is carried out in vulcanizing kettles, in which the object being rubberized is subjected to saturated vapor or hot air at a predetermined temperature. In some cases the rubberized apparatus itself can serve as the vulcanizing kettle if it operates under pressure. This is known as a closed method of vulcanization.

The increase of temperature and pressure in the vulcanizing process is carried out in accordance with a program which has been determined for each brand of rubber.

It is considerably easier to vulcanize without pressure by the open method, with hot vapor, air, water or a 40% solution of calcium chloride, heated to boiling. However, only a few rubbers can be vulcanized by this method; in particular, those based on nairite and butyl rubber.

A more progressive method of rubberizing is the use of solutions and pastes. This makes it possible to use the methods which are used to apply colored-lacquer coatings and to protect objects of complicated, as well as simple, shapes<sup>82</sup>. In order that this be practical, it is necessary that the rubbers dissolve readily and form concentrated, but not viscous, solutions which can be applied, like lacquers, by brushing, spraying, pouring or dipping.

An example of this type of rubber is chloroprene rubber which has been previously digested and is therefore readily soluble. This material has a lower molecular weight than usual and is called liquid nairite (VTU LU-109--61)(in the USA this type of rubber is called KNR liquid neoprene)<sup>83,96</sup>.

A 67-70% solution of the rubber mixture is applied to the surface by brushing, pouring or dipping. The prepared surface is covered with two layers of chloronairite primer (VTU LU-108--61). Each of these layers is aged for 15-20 min and then no less than three layers of liquid nairite are applied. Each layer is maintained at 20°C for at least two hours and the final layer is allowed to dry for three days.

The coating is vulcanized for 18-24 hours at 100°C and normal pressure by the open method, in a chamber of any kind with enclosed heating. The elastic rubber coating obtained in this way has a thickness of 1.0-1.5 mm. It has an adhesion to steel of 35-45 kgf/cm<sup>2</sup> (at the break-away point) and it has good protective properties. Sometimes more concentrated (80-90%) nairite compounds are used. These are pastes which are applied to the surfaces by spatulas or sprayers of various designs. Pastes of this kind are used to make hermetic seals.

In addition to liquid nairite, liquid low-molecular-weight rubbers are used for rubberizing from solutions or pastes. This type of coating includes rubber mixtures based on liquid thiokols: hermetics U-30M and UT-31, which are applied to surfaces being protected or sealed by spatula or by sprayer. Thiokol coatings are vulcanized in air under ordinary conditions. Thiokols can be used to protect or seal not only metals, but also concrete and other surfaces<sup>41,84</sup>.

The properties of vulcanized coatings based on liquid nairite and thiokol

hermetics are listed in Table 48.

Legend for Table 48:

- A - Properties; B - Vulcanized liquid nairite; C - Thiokol hermetics;  
 1 - Density,  $\text{g/cm}^3$ ; 2 - Limit of strength under tension,  $\text{kgf/cm}^2$ ;  
 3 - Relative elongation, %; 4 - Residual elongation, %; 5 - Wearability,  $\text{cm}^3/\text{kwh}$ ; 6 - Brittleness temperature,  $^{\circ}\text{C}$ ; 7 - Adhesion to steel (through a primer) at the break-away point,  $\text{kgf/cm}^2$ .

Показатели	Вулканизированный жидкий наирит	Тиokolовые герметики	
		У-30М	УТ-31
1 Плотность, $\text{г/см}^3$ . . . . .	1,3—1,5	1,2—1,4	1,5—1,7
2 Предел прочности при растяжении, $\text{кгс/см}^2$ . . . . .	70—90	30—35	35—40
3 Относительное удлинение, % . . . . .	200—230	300—400	450—550
4 Остаточное удлинение, % . . . . .	2—8	2—10	3—10
5 Истираемость, $\text{см}^3/\text{кат} \cdot \text{ч}$ . . . . .	430—550	1550—1650	1740—1970
6 Температура хрупкости, $^{\circ}\text{C}$ . . . . .	—30	—42	—45
7 Адгезия к стали (через грунт) на отрыв, $\text{кгс/см}^2$ . . . . .	35—50	до 28	18—20

Table 48. Physical and mechanical properties of thiokol hermetics and vulcanized coatings based on liquid nairite.

Colored-lacquer coatings. Painting with lacquers, enamels and paints is used mainly for the protection of the exteriors of chemical apparatus and buildings. It is used to a lesser degree for internal protective coatings for apparatus which is in contact with aggressive media<sup>51,53</sup>.

The best method of applying colored-lacquer coatings is by spraying with compressed air, fed through a special paint sprayer. They can also be spread adequately by the simple brush method. In addition, the methods of dipping and pouring are used. Fillers and primers can be applied by means of a spatula.

Two developing methods of applying colored-lacquer materials are painting in an electric field and the method of electrophoresis when water-emulsion paint compositions are used. Paint particles which fall into a high-intensity electric field acquire a charge and precipitate onto the surface being painted, the latter having a charge of opposite sign.

In the case of electrophoresis, particles precipitate out of an emulsion under the influence of a constant current which is supplied by an external source. The mechanization and automation of the processes, which are being improved constantly, are of great value in obtaining colored-lacquer protective coatings.

The details of the application technique depend on the nature of the lacquer or enamel. Perchlorovinyl coatings are applied in many layers, with intermediate drying and final drying of the last layer for not less than 6 days at room temperature<sup>78</sup>.

Bituminous-oil lacquers are applied in no less than two coats and the drying time of the film at 18-20°C amounts to 24-48 hours, depending on the brand of the lacquer.

Bakelite lacquers are solutions of phenol-formaldehyde resin in ethyl alcohol. To obtain chemically stable coatings, they are applied in 3-4 layers to prepared surfaces which have been cleaned to a luster. The first, prime coat (normally with a filler) is applied with a brush and the subsequent layers (of normal paint consistency) are applied by a sprayer. The filler is added to the primer in order to improve the adhesion of the lacquer to the metal, and to the covering layers in order not to impair the wearability of the coating.



Bakelite coatings are dried by gradual heating, with a pause every 10-15 minutes. The first and second layers are heated to 100°C and the third to 130°C.

Epoxide lacquers and enamels may be hardened cold with polyamines or at 100-120°C with the anhydrides of phthalic or maleic acids. Cold-setting epoxide coatings are most promising for protection from corrosion. Epoxide colored-lacquer materials are supplied in the form of two separate compounds: epoxide fillers or enamels with all of their components, and a setting solution which is added to the first compound immediately before use.

For fillers E-4020 and E-4021, a 50% solution of hexamethylenediamine is used as a hardener. The setting process takes 24 hrs at 18-20°C and 7-8 hrs at 50-70°C. Fillers are applied in several coats, since the thickness of each layer amounts to no more than 0.5 mm.

The commercial enamels OEP-4171 and OEP-4173 are also hardened with hexamethylenediamine in two hours at 120°C, in accordance with TU. They may also be hardened at room temperature, but a longer time is required (24 hrs for each coat and several days for the last). Moreover, the protective properties of cold-hardened enamels are somewhat poorer than those of enamels which have been hardened at higher temperatures.

Protection with fettling tiles<sup>67</sup>. Fettling with inlaid materials is used for the protection of large-scale apparatus: tanks, columns, autoclaves and other equipment. The first step of the fettling process is the application of a layer of plaster, cement or concrete binding material (so-called filler) to the prepared metal surface. After this layer has dried, the fettling tiles are embedded in plaster, which forms a layer of thickness 5-8 mm under the tiles and fills the cracks between them. The fettling is dried, and in some

cases the seams are subjected to acidification (for operation in acidic media). The fettling is done in one, two or more layers. In recent years there has been an increase in the use of combination linings, in which a sublayer of polyisobutylene is applied to the apparatus before fettling.

For fettling they use silicate materials (acid-resistant brick, ceramic tile, so-called "metlakh" tiles, acid-resistant and heat-acid-resistant ceramic tile, diabase and basalt cast-stone tile and, less frequently, glass and porcelain tile) and also organic materials (carbon-graphite tile, impregnated graphite and antegmite). Arzanite or silicate plaster is used as the binder and for filling cracks.

In contrast to other materials which are used for fettling, graphitic materials are thermally-conducting, which is a necessary condition for the protection of heat-exchange equipment.

In addition to the protective coatings enumerated above, which involve the use of nonmetallic materials of organic as well as inorganic origin, acid-resistant coatings of cements, concrete and bitumens are also used<sup>33</sup>.

The protection of cast-iron and steel items by enameling is of great importance in the construction of chemical apparatus. The methods of enameling are classified as wet or dry. A primer enamel of special composition is applied to the metallic surface first. This compensates for the mechanical and thermal stresses which arise between the metal and the enamel coating. Then several coats (usually three or four) of covering enamel are applied, with partial drying of each coat and final annealing of the enameled object at 850-900°C. The necessity of annealing limits the possibility of enameling large-scale equipment.

In addition to the well-known method of enameling with subsequent annealing in a furnace, a new method of enameling in an electromagnetic field with induction currents has become increasingly accepted in recent years. In this case the enameling is not done in furnaces, but on automatically-operated mechanical benches and stands. Domestic industries use this method to produce enameled pipe with flanges (with diameters of two-three inches and lengths up to two meters) and matching tees<sup>26</sup>.

For enameling chemical equipment, special brands of acid-resistant covering enamels are used: 105, 141, 143 and others. The finished enameled items must be tested for continuity of the coatings. To verify the quality of the enamel (at the time of application), special samples are tested to determine the heat- and acid-resistance and several other properties.

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## Chapter III

### CORROSION-RESISTANCE OF METALS AND NONMETALLIC MATERIALS

This chapter contains diagrams<sup>132</sup> of the stability of several materials in hydrochloric and sulfuric acids (Figures 17 and 18) and a table of the corrosion-resistance of common materials in various inorganic and organic media.

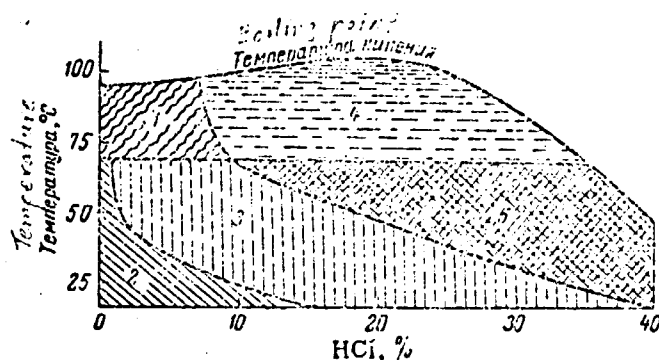


Fig. 17. Diagram of the stability of materials in hydrochloric acid, according to the data of G. A. Nelson (132) (the regions of stability are shaded):

- 1 - khastelloy V, tantalum, silver, platinum, monel metal (in the absence of air), glass, graphite;
- 2 - khastelloy V, tantalum, silver, platinum, glass, graphite, rubbers, faolite, saran, nickel (in the absence of air), monel metal, copper, silicon bronze;
- 3 - khastelloy V, tantalum, platinum, silver, silicon bronze, glass, graphite, faolite, saran, rubbers;
- 4 - khastelloy V, tantalum, platinum, silver, glass, graphite;
- 5 - khastelloy A and V, tantalum, silver, platinum, glass, graphite, faolite, saran, rubbers.

All of the materials included in the table are arranged by groups in the following order:

Group I -- metallic alloys based on iron:

steels

carbon;

chrome, containing 13% chromium;



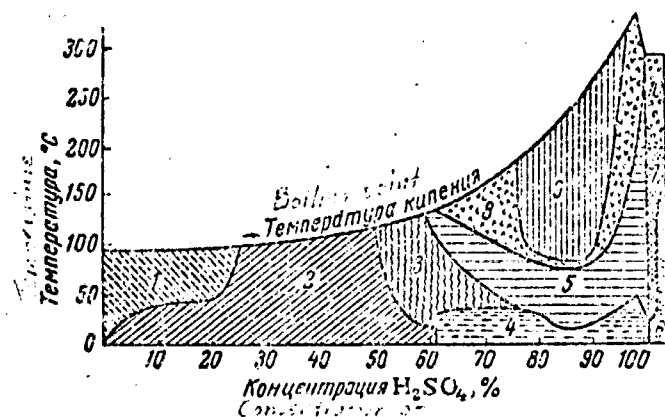


Fig. 18. Diagram of the stability of materials in sulfuric acid, according to the data of G. A. Nelson (132) (the regions of stability are shaded):

1 - lead, khastelloy V and D, steels of the type OKh23N28M3D3T, glass, graphite, faolite, rubbers (up to 77°C), copper (in the absence of air), monel metal, aluminum bronzes; 2 - lead, silicon cast iron, khastelloy V and D, steels of the type OKh23N28M3D3T (up to 66°C), glass, graphite, faolite, rubbers (up to 77°C), copper (in the absence of air), monel metal, aluminum bronzes; 3 - lead, khastelloy V and D, steels of the type OKh23N28M3D3T (up to 66°C), silicon cast iron, monel metal (in the absence of air), glass, graphite; 4 - lead, steel, silicon cast iron, khastelloy V and D, steels of the type OKh23N28M3D3T, glass, graphite (up to a concentration of 96%); 5 - silicon cast iron, khastelloy V and D, lead (up to 80°C), steels of the type OKh23N28M3D3T (up to 66°C), glass, graphite (up to 80°C and a concentration of 96%); 6 - steel, khastelloy S, steels of the types 18-8 and OKh23N28M3D3T; 8 - silicon cast iron, khastelloy V and D, glass; 9 - silicon cast iron, glass; 10 - glass.

Group I (con't):

chrome, containing 17-25% chromium;

chrome-nickel, with decreased nickel content, type Kh21N5T;

chrome-nickel of type Kh18N10T;

chrome-nickel, containing molybdenum, type Kh17N12M2T;

chrome-nickel, containing molybdenum and copper, type OKh23N28M3D3T;

cast iron:

gray;

silicon.

Group II - non-ferrous metals and alloys:

aluminum;

copper;

bronzes

aluminum;

tin;

brass;

nickel;

nickel-copper alloy (monel metal);

nickel-molybdenum alloys of the type N70M27;

lead;

silver;

tantalum;

titanium;

zinc.

Group III - polymerization plastics:

polyisobutylene;

polyethylene;

polypropylene;

polystyrene;

polymethylmethacrylate (organic glass);

polyformaldehyde;

polyvinylchloride (viniplast);

polytrifluoroethylene (fluoroplast-3);

polytetrafluoroethylene (fluoroplast-4);

asbovinyl.

Group IV - polycondensation plastics and resins:

polyamides;

**Group IV (con't):**

- polyester resins;
- chlorinated polyester -- pentoplast;
- polycarbonates;
- phenoplasts
- textolite;
- faolite;
- arzamite plasters;
- epoxide resins.

**Group V - resins based on rubbers:**

- natural;
- butadiene-styrene;
- butadiene-nitrile;
- butyl rubber;
- polysulfide;
- fluorinated rubbers;
- chlorosulfonated polyethylene;
- chloroprene.

**Group VI - colored-lacquer materials:**

- bakelite lacquers;
- bituminous mastics and lacquers;
- perchlorovinyl lacquers and enamels.

**Group VII - materials of inorganic origin:**

- natural acid-resistant materials;
- glass;
- acid-resis' at enamel;
- acid-resistant ceramic;
- porcelain;

Group VII (con't):

silicate cements, concretes, plasters.

Group VIII - other materials:

wood;

antegnite (graphitoplast);

impregnated graphite;

carbon.

Information on the corrosion-resistance of various materials is given in the table for each particular aggressive medium, with an evaluation of the stability at a given temperature or within a specified range of temperatures. When there is no information on the stability of a particular material, its name is omitted from the table.

The aggressive media are listed in alphabetical order. Inorganic media are considered first, and then organic media.

Media for which there is only a small quantity of data on the stability of materials are not considered separately. Data of this category are listed under media of similar nature, with appropriate notations to this effect.

For salts, bases and acids there are entries which give the concentrations of the saturated ( $T = 20^{\circ}\text{C}$ ) aqueous solutions for which the data on corrosion-resistance are valid.

In the absence of notes to the contrary, the stability rating applies to any intermediate concentration within the limits indicated for the medium in question. For cases in which the corrosion-resistance of the material is strongly dependent on the concentration of the medium (acids, for example), the concentration for which the data apply is given after the name or an appropriate explanation is given in the remarks.

The concentration of a solution for which data on corrosion-resistance are quoted may exceed the concentration indicated in the characteristics of the medium; and likewise the temperature limit of utilization may be higher than the boiling point. This is the result of a change of conditions: temperature, pressure, etc.

In order to facilitate the location of salts in the table of corrosion-resistance, their technical (international) names are given below:

Соли	Химическая Формула	Техническое (международное) название
Азотистокислые . . . . .	$\text{MeNO}_2$	Нитриты 1
Азотнокислые . . . . .	$\text{MeNO}_3$	Нитраты 2
Бромистые . . . . .	$\text{MeBr}$	Бромиды 3
Двуххромовокислые . . . . .	$\text{Me}_2\text{Cr}_2\text{O}_7$	Бихроматы 4
Иодистые . . . . .	$\text{MeI}$	Иодиды 5
Иодноватокислые . . . . .	$\text{MeIO}_3$	Иодаты 6
Кремнекислые . . . . .	$\text{Me}_2\text{SiO}_3$	Силикаты мета 7
Кремнефтористые . . . . .	$\text{Me}_2\text{SiF}_6$	Фторсиликаты 8
Марганцовокислые . . . . .	$\text{MeMnO}_4$	Перманганаты 9
Надсернокислые . . . . .	$\text{Me}_2\text{S}_2\text{O}_8$	Персульфаты 10
Роданистые . . . . .	$\text{MeNCS}$	Тиоцианаты 11
Сернистокислые . . . . .	$\text{Me}_2\text{SO}_3$	Сульфиты 12
Сернистокислые кислые . . . . .	$\text{MeHSO}_3$	Бисульфиты 13
Сернистые . . . . .	$\text{Me}_2\text{S}$	Сulfиды 14
Серноватистокислые . . . . .	$\text{Me}_2\text{S}_2\text{O}_3$	Гипосульфиты 15
Сернокислые . . . . .	$\text{Me}_2\text{SO}_4$	Сульфаты 16
Сернокислые кислые . . . . .	$\text{MeHSO}_4$	Бисульфаты 17
Углекислые . . . . .	$\text{Me}_2\text{CO}_3$	Карбонаты 18
Углекислые кислые . . . . .	$\text{MeHCO}_3$	Бикарбонаты 19
Уксуснокислые . . . . .	$\text{Me}(\text{CH}_3\text{COO})$	Ацетаты 20
Фосфорнокислые . . . . .	$\text{Me}_3\text{PO}_4$	Фосфаты 21
Фтористые . . . . .	$\text{MeF}$	Фториды 22
Хлористые . . . . .	$\text{MeCl}$	Хлориды 23
Хлорноватистокислые . . . . .	$\text{MeOCl}$	Гипохлориты 24
Хлорноватокислые . . . . .	$\text{MeClO}_2$	Хлораты 25
Хлорнокислые . . . . .	$\text{MeClO}_3$	Перхлораты 26
Хромовокислые . . . . .	$\text{Me}_2\text{CrO}_4$	Хроматы 27
Цианистые . . . . .	$\text{MeCN}$	Цианиды 28
Щавелевокислые . . . . .	$\text{Me}_2(\text{COO})_2$	Оксалаты 29

Names of salts found in the table of the corrosion-resistance of materials.

Legend for table (Translator's note: Only the international names are translated, since most of the Russian names have no other common equivalents):

- 1 - Nitrites; 2 - Nitrates; 3 - Bromides; 4 - Dichromates;  
5 - Iodides; 6 - Iodates; 7 - Metasilicates; 8 - Fluosilicates;

9 - Permanganates; 10 - Persulfates; 11 - Thiocyanates; 12 - Sulfites;  
13 - Bisulfites; 14 - Sulfides; 15 - Hyposulfites; 16 - Sulfates;  
17 - Bisulfates; 18 - Carbonates; 19 - Bicarbonates; 20 - Acetates;  
21 - Phosphates; 22 - Fluorides; 23 - Chlorides; 24 - Hypochlorites;  
25 - Chlorates; 26 - Perchlorates; 27 - Chromates; 28 - Cyanides;  
29 - Oxalates.

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For organic media the characteristics are the melting point and boiling point of the medium.

Information on the stability of materials is given for individual substances.

For organic acids which are soluble in water, the stabilities of materials in aqueous solutions of these acids are listed.

When data on the corrosion-resistance of materials correspond to boiling points (b. p.), they refer to the boiling points of inorganic and organic liquids or of aqueous solutions of inorganic and organic compounds.

The following conventional symbols have been adopted for rating the corrosion-resistance of materials:

B - completely stable;

X - stable;

O - slightly stable for metallic materials; relatively stable for other materials;

H - unstable.

In addition, double symbols are encountered in the ratings of corrosion-resistance of materials: for example, B-X, B-O, X-O, etc. These indicate changes of stability. The reasons for the changes are given in the appropriate

"Remarks" columns. When there are no remarks, the change of stability is caused by an increase of temperature.

If a rating of B, X, O or H is given in the "Stability" column and a footnote to this column refers to a change of stability in relation to various factors (temperature, concentration), this means that the change in the rate of corrosion falls within the limits of the corresponding rating (for example, 0.1-1 mm/yr for the rating X).

The corrosion-resistance of the materials of each group is evaluated differently.

Metals and alloys. Metals and alloys (groups I and II) are rated on a five-point scale of corrosion-resistance (see introduction), with the distinction that metals which corrode at rates greater than 3.0 mm/yr are referred to one group instead of two and are rated as unstable, practically unsuitable for use. This rating method agrees with data from the foreign reference literature on the corrosion-resistance of metals and alloys<sup>102,111,128,132</sup> and with the maximum allowable values of corrosion permeability which have been adopted by the chemical industry<sup>77</sup> (see table on page 9).

In the table below, the adopted system for rating the corrosion-resistance of metals and alloys is compared with the five-point and ten-point scales.

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Legend for table:

A - Adopted stability rating; B - Rate of corrosion, mm/yr; C - Stability group; D - Stability rating on five-point scale; E - Stability rating on ten-point scale (GOST 5272-50);

1 - Completely stable (B); 2 - Very stable (point 1); 3 - From completely

stable to stable (points 1-5); 4 - Stable (X); 5 - Stable (point 2);  
 6 - Decreased stability (points 6,7); 7 - Slightly stable (O);  
 8 - Decreased stability (point 3); 9 - Slightly stable (point 8);  
 10 - Unstable (H); 11 - From slightly stable to unstable (points 4,5);  
 12 - From slightly stable to unstable (points 9,10).

A. Принятая оценка стойкости		Д	Е
В скорость коррозии мм/год	Г группы стойкости	Оценка стойкости по пятибалльной шкале	Оценка стойкости по десятибалльной шкале (ГОСТ 5272-50)
<0,1	1. Вполне стойкие (В)	2. Весьма стойкие (балл 1)	3. От совершенно стойких до стойких (баллы 1-5)
0,1-1	4. Стойкие (Х)	5. Стойкие (балл 2)	6. Пониженностойкие (баллы 6,7)
1-3	7. Малостойкие (О)	8. Пониженностойкие (балл 3)	7. Малостойкие (балл 8)
>3	9. Нестойкие (Н)	10. От малостойких до нестойких (баллы 4,5)	8. От малостойких до нестойких (баллы 9,10)

Nonmetallic polymeric materials. In rating the corrosion-resistance of nonmetallic polymeric materials (groups III, IV, V, VI), changes of mass or volume under the influence of the aggressive medium are considered. Changes of mechanical properties are also considered when data are available.

For rubbers, the change of elasticity after exposure to the aggressive medium is also taken into consideration (if the relative elongation at rupture amounts to less than 100%, the rubber is considered to be unstable in the medium in question).

In evaluating the corrosion-resistance of nonmetallic materials of inorganic origin and other materials (groups VII and VIII), the following categories are used: stable (B or X), relatively stable (O) and unstable (H). This is due fact that the evaluation of, for example, natural and silicate materials is ordinarily confined to the determination of acid-resistance and



water-absorbance. The limit of strength under compression or tension is tested only for load-bearing structures. The acid-resistance of these materials should be at least 97-98%.

In evaluating the chemical stability of enamel coatings, the loss of mass in mg per cm<sup>2</sup> of surface is considered and external changes are also noted (dullness, roughness).

The table on page 111 shows a comparison of the qualitative ratings (using the adopted symbols) of the corrosion-resistance of materials in the various groups with the quantitative ratings or with the characteristics of the surfaces (in the case of enamel coatings). There is also an indication of the use of the materials in each category in relation to their corrosion-resistance.

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Legend for table:

A - Rating of corrosion-resistance; B - Metals (groups I, II);  
C - Rate of corrosion, mm/yr; D - Use; E - Nonmetallic polymeric materials (groups III, IV, V, VI); F - Change of mass, %; G - Change of strength, %; H - Nonmetallic materials (groups VII, VIII);  
I - Enamels; J - Silicate and other materials; K - Condition of surface; L - Acid-resistance, %;  
1 - For any apparatus or machinery; 2 - For equipment of simple construction; 3 - Only for replaceable parts; 4 - For parts which are changed frequently (after experimental testing); 5 - Decompose under the influence of the medium and are unsuitable for use; 6 - Unchanged; 7 - Slightly dull; 8 - Dull (rough); 9 - Decompose; 10 - Unlimited; 11 - Limited use (under certain conditions); 12 - Not recommended for use.

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А Описание коррозионной стойкости (условия эксплуатации)	Б Металлы (группы I, II)		В Неметаллические полимерные материалы (группы III, IV, V, VI)				Г Неметаллические материалы (группы VII, VIII)			
	С скорость коррозии мм/год	Д применение	Е изменение массы %	Ж изменение прочности %	З изменение прочности %	И эмали состояние по-верхности	К силикатные и прочие мате-риалы кислотостой-кость, %	Л применение		
В	<0,1	Для любых / аппаратов и машин	±0,2	±5	Без изме-нений	>97	Без ограничений			
Х	0,1—1	Для оборудова-ния неслож-ных конструк-ций	±10	±10—15	—	—	—			
О	1,0—3	Только для сложных де-талей	±15	±15—20	Слабато-тая	<97	Ограничено при-менены (при определенных условиях)			
Н	>3	Для часто сме-няемых дета-лей (после эк-сперименталь-ной проверки)	При воздействии среды разрушаются и для ис-пользования непригодны		Матовая (шерохова-тая)	Разрушают-ся	Применять не рекомендуется			